Energy Research and Development Division
FINAL PROJECT REPORT

Residential Water Heating Program

Facilitating the Market Transformation to Higher Efficiency Gas-Fired Water Heating

APPENDICES

Prepared for: California Energy Commission

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PREFACE

The California Energy Commission Energy Research and Development Division supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The Energy Research and Development Division conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

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- Energy Systems Integration
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- Renewable Energy Technologies
- Transportation

Residential Water Heating Program is the final report for the Residential Water Heating Program (contract 500-08-060) conducted by the Gas Technology Institute The information from this project contributes to Energy Research and Development Division's Buildings End-Use Energy Efficiency Program.

For more information about the Energy Research and Development Division, please visit the Energy Commission's website at www.energy.ca.gov/research/ or contact the Energy Commission at 916-327-1551.

ABSTRACT

Water heating is the single most significant residential end use for natural gas in California. Natural gas is used to heat water in nearly 90 percent of homes and represents 49 percent of the average 354 therms of annual household consumption per the 2009 Residential Appliance Saturation Survey. Nearly 90 percent of California's 12.3 million households use natural gas water heaters, with 2,111 million therms consumed yearly overall, according to the Energy Information Administration. An average California household could see its annual natural gas water heating consumption drop 35 percent using an advanced water heater combined with an improved distribution piping system.

This research program has helped facilitate the overall goal of reducing natural gas consumption for residential water heating in California with a broad-based set of closely linked project activities:

- Developing an integrated hot water generation and distribution system analysis tool, efficient water heating equipment and piping system best practices, and a design guide.
- Revisions for water heater standard testing and rating methods and updates to building and energy efficiency codes.
- Laboratory evaluations of water heating equipment and hot water distribution piping.
- Field performance monitoring of water heaters and surveys of consumer behavior and plumber distribution system installation practice.
- Advanced water heating system training for plumbing and other trades.

These findings could help facilitate a 3 to 4 percent reduction in statewide natural gas consumption for residential water heating approaching 86 million therms, along with significant emissions reductions and hot water requirements cumulatively through 2025, based on calculations by the Lawrence Berkeley National Laboratory. However, recent sustained lower natural gas prices, which were not anticipated at the outset of this program, will limit the cost-effectiveness of many of these efficiency improvements and will slow the market transformation process for achieving these consumption reductions.

Keywords: water heating, hot water distribution, models, field tests, lab evaluations, codes, standards, best practices.

Please use the following citation for this report:

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Overview

This tutorial describes how to use the binary export version of the model. The binary version of the tankless water heater model consists of eight files. All of the files must be located in the same folder.

- StorageTankExample.exe: This file is the model that was exported from Dymola. Running this executable file will perform the simulation.
- libdsdll.dll: This dynamic link library file is necessary to run Modelica simulations.
- dsin.txt: This file is used to describe the simulation parameters. Possible inputs include simulation start time, stop time, solver tolerance and which solver should be used. This file can be edited using a standard text editor (this example uses Notepad) and detailed discussion is provided in section 10.2.
- StorageExampleParameters.txt: This file allows the user to change the parameters describing the heater itself. Parameters available in this file include thermal capacitance, UA value, steady state efficiency, maximum heat input rate, and more. The parameters can be edited using a standard text editor (this example uses Notepad). This file can be edited using a standard text editor (this example uses Notepad) and detailed discussion in provided in section 10.3.
- StorageTankDrawProfile.txt: This text file is used to describe the flow pattern in the simulation. A detailed discussion of how this file is provided in section 10.4. The file can be opened/edited with a standard text editor (this example uses Notepad). All following files are edited in the same manner.

Changing the Simulation Parameters

The simulation parameters are available in the file dsin.txt. All of the inputs that need to be edited are at the top of the file. An image showing the useful part of dsin.txt is shown in Figure 1.

The important inputs are the start time, stop time, tolerance, and algorithm.

The start time states the starting time of the simulation. It changes how Dymola references the time-varying input tables but does not perform calculations to change the initial conditions. For example, if a simulation at 1500s the initial temperature of the heat exchanger will be the same as if the simulation started at 0s regardless of what happened in seconds 0-1499.

The stop time states the final time of the simulation in seconds.

The tolerance entry states the convergence tolerance for the solver.

The algorithm input is used to state the solver used in the simulation. A table is provided stating what solvers are available, which numbers are used to select them, and providing a brief description of the solver. Algorithm 15, which is not described in the table, represents the algorithm “radau IIa – 5 order stiff.” This algorithm, with a tolerance of 1e-6, is recommended by the LBNL Simulation Research Group as being the fastest and most robust solver for thermo-fluid systems [**Error! Reference source not found.**].

dsin.txt - Notepad

File Edit Format View Help

```
#1
char Aclass(3,24)
Adymosim
1.4
Modelica experiment file


#    Experiment parameters
double experiment(7,1)
       0                   # StartTime    Time at which integration starts
                           #              (and linearization and trimming time)
    1000                   # StopTime     Time at which integration stops
       0                   # Increment    Communication step size, if > 0
     100                   # nInterval    Number of communication intervals, if > 0
  1.000000000000000E-006   # Tolerance    Relative precision of signals for
                           #              simulation, linearization and trimming
       0                   # MaxFixedStep Maximum step size of fixed step size
                           #              integrators, if > 0.0
      15                   # Algorithm    Integration algorithm as integer (1...28)
                           #
                           #             | model|       |        | dense | state |
                           # Algorithm   | typ  | stiff | order  | output| event |
                           # ------------+------+-------+--------+-------+-------+
                           #  1 | deabm  |  ode |   no  |  1-12  |  yes  |   no  |
                           #  2 | lsode1 |  ode |   no  |  1-12  |  yes  |   no  |
                           #  3 | lsode2 |  ode |  yes  |  1-5   |  yes  |   no  |
                           #  4 | lsodar |  ode |  both |1-12,1-5|  yes  |  yes  |
                           #  5 | dopri5 |  ode |   no  |   5    |   no  |   no  |
                           #  6 | dopri8 |  ode |   no  |   8    |   no  |   no  |
                           #  7 | grk4t  |  ode |  yes  |   4    |   no  |   no  |
                           #  8 | dassl  |  dae |  yes  |  1-5   |  yes  |  yes  |
                           #  9 | odassl | hdae |  yes  |  1-5   |  yes  |  yes  |
                           # 10 | mexx   | hdae |   no  |  2-24  |   no  |   no  |
                           # 11 | euler  |  ode |   no  |   1    |   no  |  yes  |
                           # 12 | rkfix2 |  ode |   no  |   2    |   no  |  yes  |
                           # 13 | rkfix3 |  ode |   no  |   3    |   no  |  yes  |
                           # 14 | rkfix4 |  ode |   no  |   4    |   no  |  yes  |
                           #>=14| others |  ode |yes/no |  2-5   |  yes  |  yes  |
                           # ---+--------+------+-------+--------+-------+-------+
                           # euler and rkfix have fixed stepsize.
```

Figure 1: dsin.txt

Changing the Heater Parameters

The parameters describing the heater can be edited in TanklessExampleParameters.txt. An image of TanklessExampleParameters.txt is shown in Figure 2.

StorageExampleParameters.txt - Notepad

File Edit Format View Help

```
DryBulbTemperature = 273.15 + 21                  // Units: K
MeanRadiantTemperature = 273.15 + 21              // Units: K
FloorTemperature = 273.15 + 15                    // Units: K
QDot_Pilot = 205                                  // Units: W
QDot_Burner = 10550                               // Units: W
T_Set = 273.15 + 50                               // Units: K
ThermostatDeadband = 12                           // Units: C
TankVolume = 0.136                                // Units: cu.m.
FlueDiameter = 0.075                              // Units: m
FlueLength = 1                                    // Units: m
InletWaterTemp = 273.15 + 15.6                    // Units: K
FlueToWaterConvectionCoefficient = 14.8           // Units: W/(sq. m. - K)
GasToFlueConvectionCoefficient = 79               // Units: W/(sq. m. - K)
TankDiameter = 0.4                                // Units: m
GasToBaseConvectionCoefficient = 210              // Units: W/(sq. m. - K)
FuelHigherHeatingValue = 51172000                 // Units: J/kg
FuelLowerHeatingValue = 46520000                  // Units: J/kg
StoichiometricAirFuelRatio = 16.20
ExcessAir = 0.5
GasSpecificHeat = 1172                            // J/(kg-K)
T_Initial = 273.15 + 55                           // Initial temperature of water in the tank. Currently only able to handle a constant temperature in all segments. Units: K
nSeg = 20                                         // Number of segments in the tank. No units
topMix = 15                                       // Segment at the top of the region which is well mixed by a 3 gpm draw. No units
```

Figure 2: StorageExampleParameters.txt

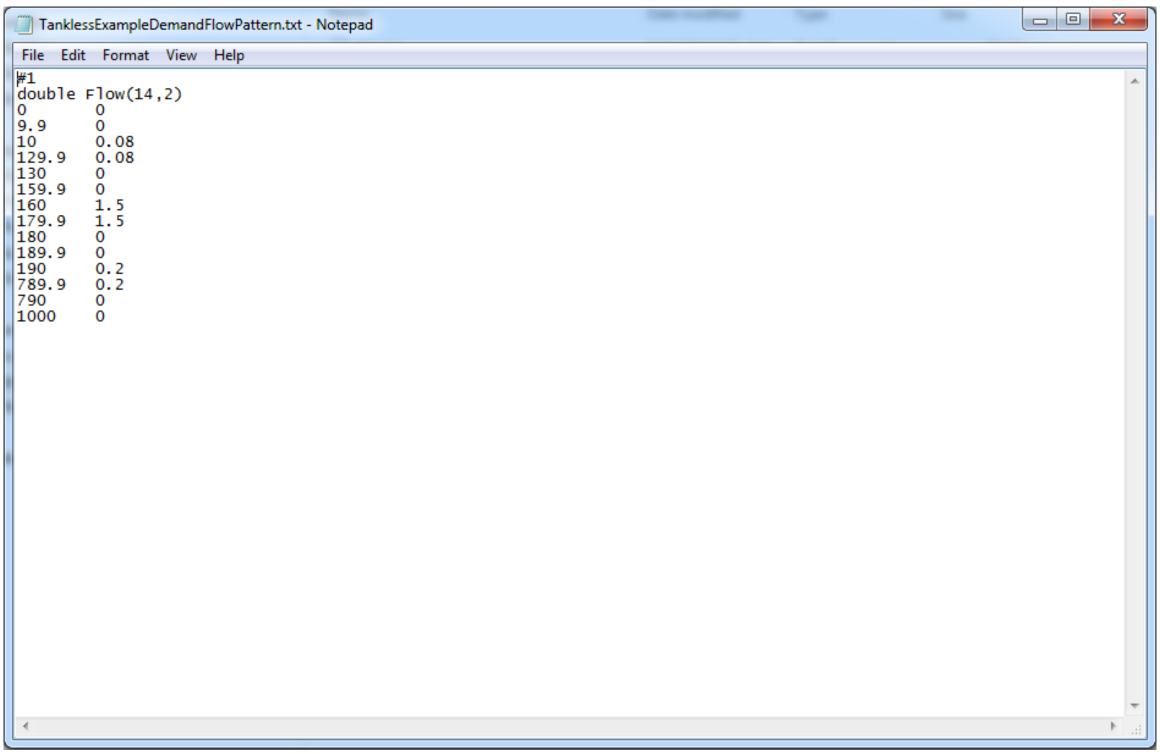
Several variables are available for editing in TanklessExampleParameters.txt. The names of the variables are included on the left hand side of the file. The value that they are equal to is stated after the equals sign, and the units for each variable are provided in the comments to the right. Any necessary notes can be made after the "//" as that designates a comment area and changes will not impact the simulation. A brief description of each input is provided here.

- DryBulbTemperature: Describes the dry bulb temperature of the ambient environment. Should be expressed in K.
- MeanRadiantTemperature: Declares the mean radiant temperature of the surrounding surfaces. Must be expressed in K.
- FloorTemperature: States the temperature of the floor that the water heater is installed on. Must be expressed in K.
- QDot_Pilot: States the heat input rate for the heater's pilot light. Must be expressed in W.
- QDot_Burner: States the heat input rate for the heater's burner. Must be expressed in W.
- T_Set: States the setpoint for the heater. Must be expressed in K.
- ThermostatDeadband: States the deadband on the thermostat. Must be expressed in SI units. The specified value refers to the entire range (i.e. 12 °C is treated as ± 6 °C).
- Tank Volume: The volume of water held in the storage tank. Must be entered in m3.
- FlueDiameter: The diameter of the flue. Must be expressed in m.
- FlueLength: The length of the flue (from the burner to the top of the heater). Must be expressed in m.
- InletWaterTemp: Temperature of mains water entering the cold side of the water heater. Must be expressed in K.
- FlueToWaterConvectionCoefficient: The convection coefficient used to characterize heat transfer between the flue wall and the water. Must be expressed in W/(m2-K).
- GasToFlueConvectionCoefficient: The convection coefficient used to characterize heat transfer between the flue gas and the flue wall. Must be expressed in W/(m2-K).
- TankDiameter: The diameter of the storage tank. Must be expressed in m.
- GasToBaseConvectionCoefficient: The convection coefficient describing heat transfer between the hot gas in the burner and the base of the heater. Must be expressed in W/(m2-K).
- FuelHigherHeatingValue: The higher heating value of the fuel used to heat the water. Must be expressed in J/kg.
- FuelLowerHeatingValue: The lower heating value of the fuel used to heat the water. Must be expressed in J/kg.
- StoichiometricAirFuelRatio: The stoichiometric air fuel ratio for the fuel used to heat the water.
- ExcessAir: The excess air fraction in the burner. Should be expressed in decimal form (Example: 10% excess air = 0.1).
- GasSpecificHeat: The specific heat of the flue gases. Should be expressed in J/(kg-K).
- T_Initial: The initial temperature of every segment in the tank. Must be expressed in K.
- nSeg: The number of segments representing the storage tank in the simulation.

- topMix: The segment at the top of the zone which is well mixed by a draw. This value is currently a constant regardless of water flow rate. Intended improvements were discussed in section 8.

Changing the Draw Profile

The draw profile is described in TanklessExampleDemandFlowPattern.txt. An image of the file is shown in Figure **3**.


TanklessExampleDemandFlowPattern.txt - Notepad

File Edit Format View Help

```
#1
double Flow(14,2)
0       0
9.9     0
10      0.08
129.9   0.08
130     0
159.9   0
160     1.5
179.9   1.5
180     0
189.9   0
190     0.2
789.9   0.2
790     0
1000    0
```

Figure 3: TanklessExampleDemandFlowPattern.txt

There are several points that should be mentioned about the table in Figure 3.

- The “#1” at the top of the table must not be changed. The simulation uses it to locate the table.
- The term “double” right below “#1” declares the data type used in the table.
- “Flow(14,2)” both gives the name of the table and states the number of rows and columns in the table. The name must not be changed as the simulation uses it to locate the table. The number of rows and columns stated must match the number of rows and columns in the table. They can be edited if the entries in the table change.
- The data in the first column represents time in seconds. All values entered must be in sequential order, meaning that no two values can be the same. The beginning and ending of draws are

treated as a change in flow rate over a very brief time period. For example, the second and third rows in the first column read “9.9” and “10” implying that the change happened over 0.1s.

- The data in the second column represents the water flow rate in kg/s. As can be seen in Figure 3, draws are started by changing the flow rate from zero to a higher value over a brief period of time (the 0.1s mentioned in the last bullet). They are stopped in the same manner.
- The time data available in the table must be as long as the simulation. If the stop time of the simulation is later than the end of the draw profile table the simulation will not run.
- Rows can be added to/removed from the table. The number of rows in the table name must be edited to reflect any changes.

The files TanklessExampleAmbientTemperature.txt, TanklessExampleInletTemperature.txt and TanklessExamplePowerSignal.txt all work in the same way as TanklessExampleDemandFlowPattern.txt.

Running the Simulation and Analyzing Results

Double clicking TanklessExample.exe will start the simulation. The simulation will open a DOS command window that provides information on the simulation as it progresses. After the simulation finishes some additional files will be generated. If the simulation completely successfully one file will be named “success.” If the simulation failed to finish it will generate a file named “failure.” The generated file named dsres.mat contains the output data from the simulation.

The output data is in a Matlab format. This tutorial will detail how to access the data using the demo version of Dymola. All of the necessary features to view and export data are available in the demo version of Dymola and no license file is required. The demo version of Dymola can be downloaded from www.dymola.com.

Upon opening Dymola switch to the simulation tab by selecting “Simulation” in the lower right hand corner. In the top menu select “Plot” followed by “Open Result…” Figure 4 shows the location of all of the buttons necessary to find “Open Result…”

Figure 4: Navigating to "Open Result..."

Navigate to the folder containing dsres.mat and open the file. Dymola will now read all of the data and make it available for plotting in the Dymola environment. The data can be exported to either a .csv or .txt file. In the variables browser (upper left hand side of the screen) there should be a top-level folder titled “dsres.mat.” Right-click on dsres.mat and select “Save Result As…” Figure 5 shows the menus necessary to navigate to “Save Result As…”

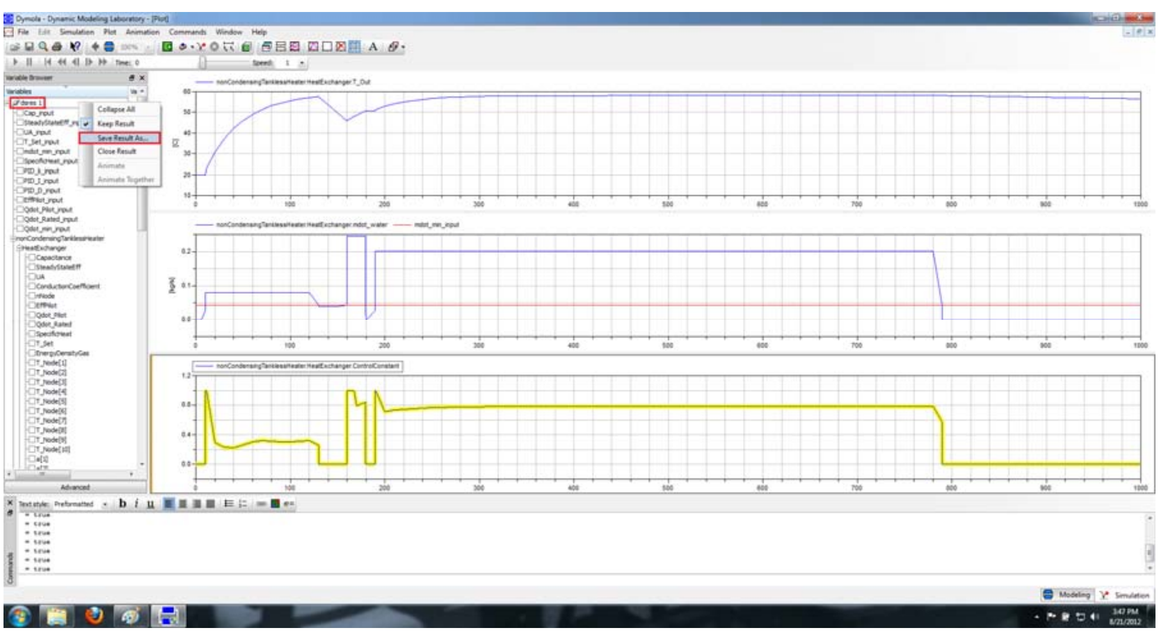


Figure 5: Navigating to "Save Result As..."

Several options will be available for exporting data, including .csv and .txt. It should be noted that the .csv option will only export the data that is plotted, and .txt should be selected if exporting all of the data is desired.

Appendix B: Advanced Tankless Water Heater Model Use Tutorial

Overview

This tutorial describes how to use the binary export version of the model. The binary version of the tankless water heater model consists of eight files. All of the files must be located in the same folder.

- TanklessExample.exe: This file is the model that was exported from Dymola. Running this executable file will perform the simulation.
- libdsdll.dll: This dynamic link library file is necessary to run Modelica simulations.
- dsin.txt: This file is used to describe the simulation parameters. Possible inputs include simulation start time, stop time, solver tolerance and which solver should be used.
- TanklessExampleParameters.txt: This file allows the user to change the parameters describing the heater itself. Parameters available in this file include thermal capacitance, UA value, steady state efficiency, maximum heat input rate, and more. The parameters can be edited using a standard text editor (this example uses Notepad).
- TanklessExampleDemandFlowPattern.txt: This text file is used to describe the flow pattern in the simulation. A detailed discussion of how this file is provided in section 8.4. The file can be opened/edited with a standard text editor (this example uses Notepad). All following files are edited in the same manner.
- TanklessExampleAmbientTemperature.txt: This file allows the user to describe the ambient temperature during the simulation. It contains a text-based table that can be edited to simulate changing ambient conditions. It is edited in the same manner as TanklessExampleDemandFlorPattern.txt.
- TanklessExampleInletTemperature.txt: This file contains a table similar to those found in TanklessExampleDemandFlowPattern.txt and TanklessExampleAmbientTemperature.txt. It is used to input the temperature of water entering the heater during the simulation.
- TanklessExamplePowerSignal.txt: This file contains a table similar table to the previous three files. It can be used to control power at the water heater. One indicates that the heater is on; zero indicates that it is not.

Changing the Simulation Parameters

The simulation parameters are available in the file dsin.txt. All of the inputs which need to be edited are at the top of the file. An image showing the useful part of dsin.txt is shown in Figure 6.

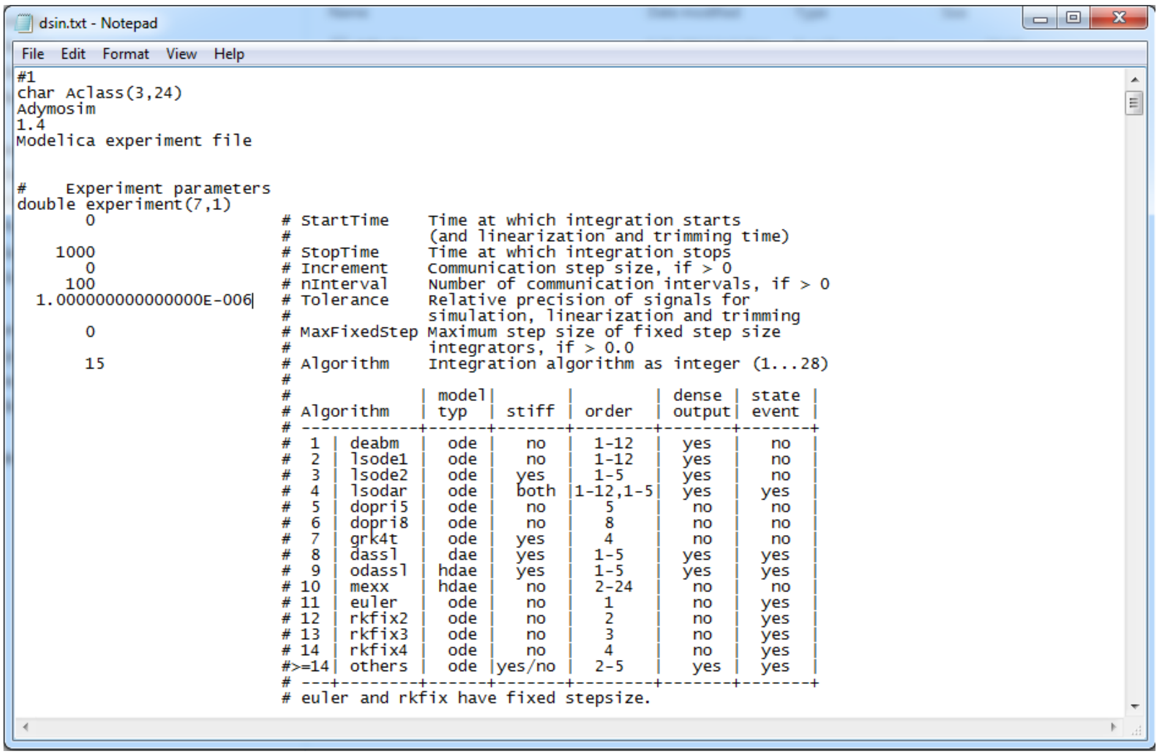
The important inputs are the start time, stop time, tolerance, and algorithm.

The start time states the starting time of the simulation. It changes how Dymola references the time-varying input tables but does not perform calculations to change the initial conditions. For example, if a simulation at 1500s the initial temperature of the heat exchanger will be the same as if the simulation started at 0s regardless of what happened in seconds 0-1499.

The stop time states the final time of the simulation in seconds.

The tolerance entry states the convergence tolerance for the solver.

The algorithm input is used to state the solver used in the simulation. A table is provided stating what solvers are available, which numbers are used to select them, and providing a brief description of the solver. Algorithm 15, which is not described in the table, represents the algorithm "radau IIa – 5 order stiff." This algorithm, with a tolerance of 1e-6, is recommended by the LBNL Simulation Research Group as being the fastest and most robust solver for thermo-fluid systems [**Error! Reference source not found.**].


dsin.txt - Notepad

File Edit Format View Help

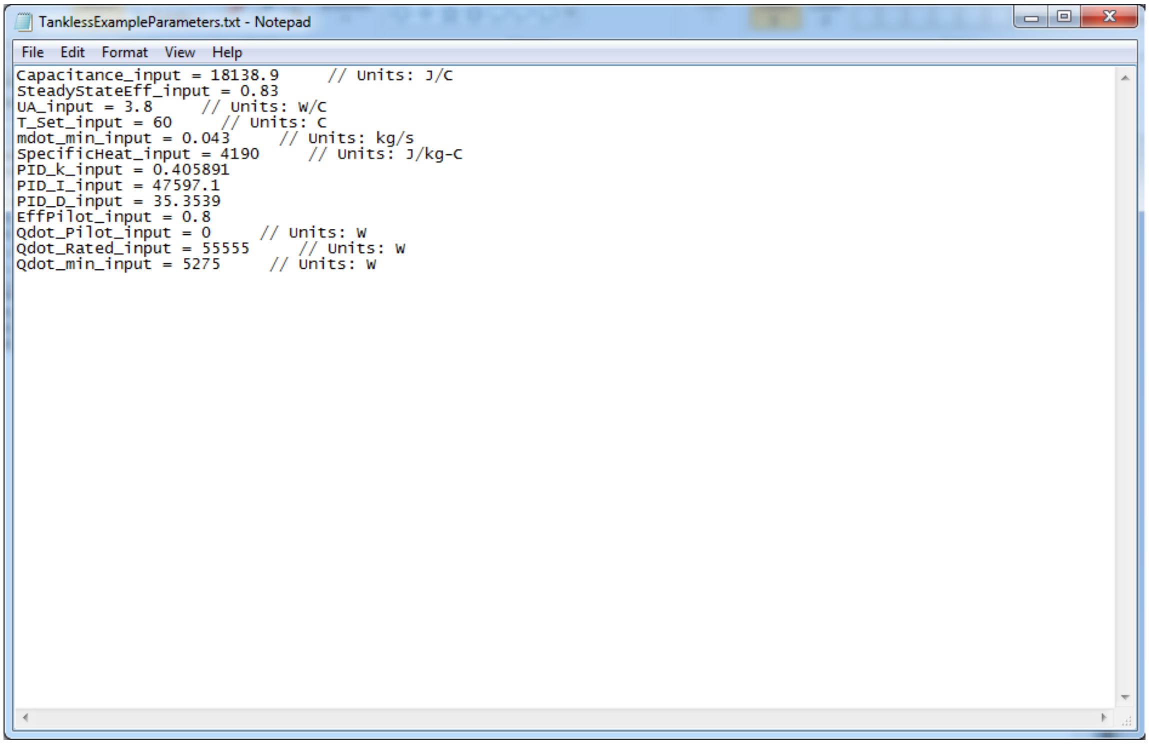
```
#1
char Aclass(3,24)
Adymosim
1.4
Modelica experiment file


#    Experiment parameters
double experiment(7,1)
       0                    # StartTime    Time at which integration starts
                            #              (and linearization and trimming time)
    1000                    # StopTime     Time at which integration stops
       0                    # Increment    Communication step size, if > 0
     100                    # nInterval    Number of communication intervals, if > 0
  1.0000000000000000E-006   # Tolerance    Relative precision of signals for
                            #              simulation, linearization and trimming
       0                    # MaxFixedStep Maximum step size of fixed step size
                            #              integrators, if > 0.0
      15                    # Algorithm    Integration algorithm as integer (1...28)
                            #
                            #             | model|       |        | dense | state |
                            # Algorithm   | typ  | stiff | order  | output| event |
                            # ------------+------+-------+--------+-------+-------+
                            #  1 | deabm  | ode  |   no  |  1-12  |  yes  |   no  |
                            #  2 | lsode1 | ode  |   no  |  1-12  |  yes  |   no  |
                            #  3 | lsode2 | ode  |  yes  |  1-5   |  yes  |   no  |
                            #  4 | lsodar | ode  |  both |1-12,1-5|  yes  |  yes  |
                            #  5 | dopri5 | ode  |   no  |   5    |   no  |   no  |
                            #  6 | dopri8 | ode  |   no  |   8    |   no  |   no  |
                            #  7 | grk4t  | ode  |  yes  |   4    |   no  |   no  |
                            #  8 | dassl  | dae  |  yes  |  1-5   |  yes  |  yes  |
                            #  9 | odassl | hdae |  yes  |  1-5   |  yes  |  yes  |
                            # 10 | mexx   | hdae |   no  |  2-24  |   no  |   no  |
                            # 11 | euler  | ode  |   no  |   1    |   no  |  yes  |
                            # 12 | rkfix2 | ode  |   no  |   2    |   no  |  yes  |
                            # 13 | rkfix3 | ode  |   no  |   3    |   no  |  yes  |
                            # 14 | rkfix4 | ode  |   no  |   4    |   no  |  yes  |
                            #>=14| others | ode  |yes/no |  2-5   |  yes  |  yes  |
                            # ---+--------+------+-------+--------+-------+-------+
                            # euler and rkfix have fixed stepsize.
```

Figure 6: dsin.txt

Changing the Heater Parameters

The parameters describing the heater can be edited in TanklessExampleParameters.txt. An image of TanklessExampleParameters.txt is shown in Figure 7.



TanklessExampleParameters.txt - Notepad

File Edit Format View Help

```
Capacitance_input = 18138.9     // Units: J/C
SteadyStateEff_input = 0.83
UA_input = 3.8     // Units: W/C
T_Set_input = 60     // Units: C
mdot_min_input = 0.043     // Units: kg/s
SpecificHeat_input = 4190     // Units: J/kg-C
PID_k_input = 0.405891
PID_I_input = 47597.1
PID_D_input = 35.3539
EffPilot_input = 0.8
Qdot_Pilot_input = 0     // Units: W
Qdot_Rated_input = 55555     // Units: W
Qdot_min_input = 5275     // Units: W
```

Figure 7: TanklessExampleParameters.txt

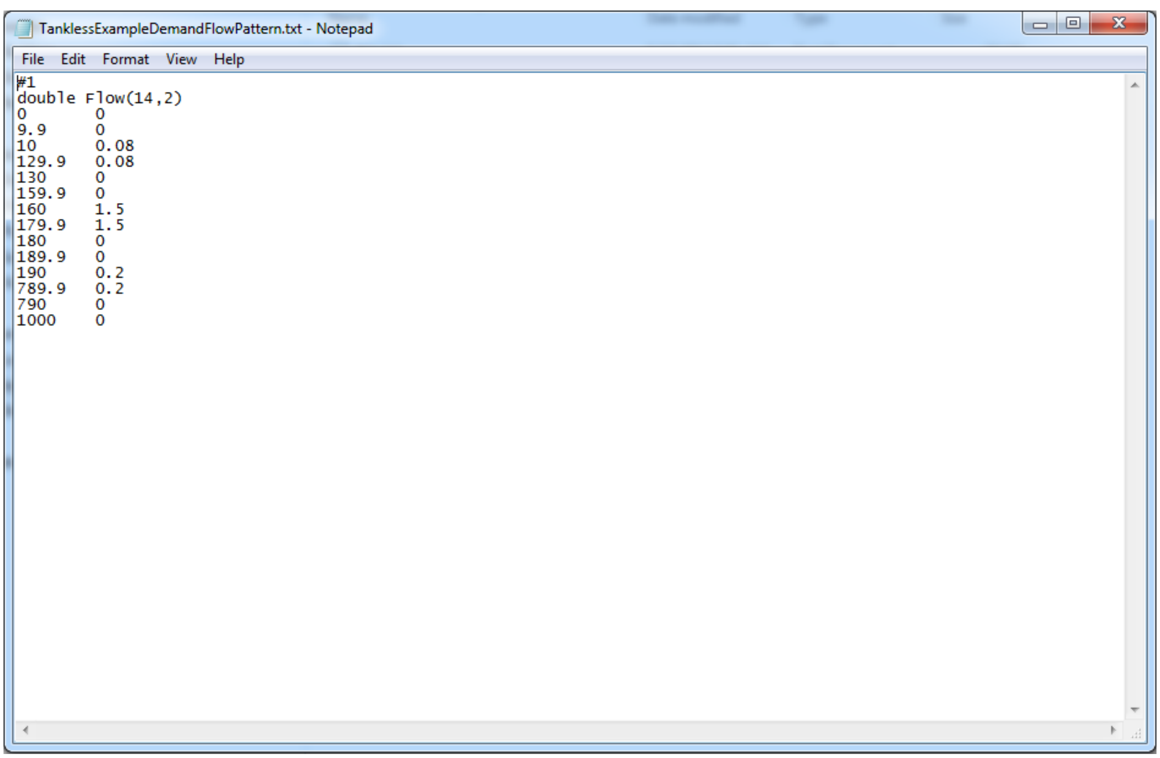
Several variables are available for editing in TanklessExampleParameters.txt. The names of the variables are included on the left hand side of the file. The value that they are equal to is stated after the equals sign, and the units for each variable are provided in the comments to the right. Any necessary notes can be made after the "//" as that designates a comment area and changes will not impact the simulation. A brief description of each input is provided here.

- Capacitance_input: Describes the thermal capacitance of the heat exchanger. It is expressed in units J/°C.
- SteadyStateEfficiency_input: Describes the steady state operating efficiency of the burner and heat exchanger. Efficiency, for this use, is defined as energy transferred to the water divided by energy entering the heater. Experimental data collected at NREL showed that the steady state thermal efficiency does not vary with flow rate, set temperature or heat draw rate [**Error! Reference source not found.**].
- UA_input: Describes the heat loss coefficient of the heater. This parameter is used to identify the rate at which the heater loses energy to the surrounding environment. It should be expressed in units of W/°C.
- T_Set_input: The setpoint of the heater. It should be expressed in °C.
- mdot_min_input: The minimum flow rate of the tankless water heater. If the water flow rate is below this value the heater will not fire. It should be expressed in kg/s.

- SpecificHeat_input: The specific heat of the fluid being heated (Water = 4190 J/kg-°C). It should be expressed in J/kg-°C.
- PID_k_input: The constant used for the proportional term in the PID controller.
- PID_I_input: The constant used for the integral term in the PID controller.
- PID_D_input: The constant used for the differential term in the PID controller.
- EffPilot_input: The efficiency of heat transfer from the pilot light. Efficiency, for this use, is defined as energy transferred to the water divided by energy entering the heater.
- Qdot_Pilot_input: The heat consumption rate of the pilot light. Entering zero will effectively simulate a heater without a pilot light. This value should be expressed in W.
- Qdot_Rated_input: The rated input heat rate of the tankless heater. If a heater has a different measured maximum heat rate that value should be entered instead. The heat input rate should be expressed in W.
- Qdot_min_input: The minimum firing rate of the tankless heater. The heater will not fire if the heat required to being the water to the set temperature is less than this value. It should be expressed in W.

Changing the Draw Profile

The draw profile is described in TanklessExampleDemandFlowPattern.txt. An image of the file is shown in Figure 8.


TanklessExampleDemandFlowPattern.txt - Notepad

File Edit Format View Help

```
#1
double Flow(14,2)
0       0
9.9     0
10      0.08
129.9   0.08
130     0
159.9   0
160     1.5
179.9   1.5
180     0
189.9   0
190     0.2
789.9   0.2
790     0
1000    0
```

Figure 8: TanklessExampleDemandFlowPattern.txt

There are several points that should be mentioned about the table in Figure 8.

- The “#1” at the top of the table must not be changed. The simulation uses it to locate the table.
- The term “double” right below “#1” declares the data type used in the table.
- “Flow(14,2)” both gives the name of the table and states the number of rows and columns in the table. The name must not be changed as the simulation uses it to locate the table. The number of rows and columns stated must match the number of rows and columns in the table. They can be edited if the entries in the table change.
- The data in the first column represents time in seconds. All values entered must be in sequential order, meaning that no two values can be the same. The beginning and ending of draws are treated as a change in flow rate over a very brief time period. For example, the second and third rows in the first column read “9.9” and “10” implying that the change happened over 0.1s.
- The data in the second column represents the water flow rate in kg/s. As can be seen in Figure 3, draws are started by changing the flow rate from zero to a higher value over a brief period of time (the 0.1s mentioned in the last bullet). They are stopped in the same manner.
- The time data available in the table must be as long as the simulation. If the stop time of the simulation is later than the end of the draw profile table the simulation will not run.
- Rows can be added to/removed from the table. The number of rows in the table name must be edited to reflect any changes.

The files TanklessExampleAmbientTemperature.txt, TanklessExampleInletTemperature.txt and TanklessExamplePowerSignal.txt all work in the same way as TanklessExampleDemandFlowPattern.txt.

Running the Simulation and Analyzing Results

Double clicking TanklessExample.exe will start the simulation. The simulation will open a DOS command window that provides information on the simulation as it progresses. After the simulation finishes some additional files will be generated. If the simulation completely successfully one file will be named “success.” If the simulation failed to finish it will generate a file named “failure.” The generated file named dsres.mat contains the output data from the simulation.

The output data is in a Matlab format. This tutorial will detail how to access the data using the demo version of Dymola. All of the necessary features to view and export data are available in the demo version of Dymola and no license file is required. The demo version of Dymola can be downloaded from www.dymola.com.

Upon opening Dymola switch to the simulation tab by selecting “Simulation” in the lower right hand corner. In the top menu select “Plot” followed by “Open Result…” Figure 9 shows the location of all of the buttons necessary to find “Open Result…”

Navigate to the folder containing dsres.mat and open the file. Dymola will now read all of the data and make it available for plotting in the Dymola environment. The data can be exported to either a .csv or .txt file. In the variables browser (upper left hand side of the screen) there should be a top-level folder titled “dsres.mat.” Right-click on dsres.mat and select “Save Result As…”

Figure **10** shows the menus necessary to navigate to “Save Result As…” Several options will be available for exporting data, including .csv and .txt. It should be noted that the .csv option will only export the data that is plotted, and .txt should be selected if exporting all of the data is desired.

Figure 9: Navigating to "Open Result..."

Figure 10**: Navigating to "Save Result As..."**

Appendix C: Best Practices Water Heater Selection Tool

Step 1: Determine Climate

From Table 1 below, select the climate that best characterizes your location. (Note that the selected climate influences both the performance of HPWHs and also the hot water load as cold water supply temperature is dependent on climate).

Step 2: Estimate Hot Water Load

Residential hot water loads are characterized as low, moderate, above average, or high. Realizing that inlet and outlet water temperatures strongly affect the water heater recovery (Btu) load, a rough approximation for the four load categories (in terms of gallons per day) is 20, 45, 65, and 110 gpd, respectively. For new construction, assume either Moderate or Above Average loads, unless more specific household information is available. For retrofit applications, try to assess the current occupant situation, or rely on the load suggestions presented in Table 1. In cases where two load categories are shown, red highlighting indicates the suggested selection. If neither selection is highlighted, either evaluate both load options or use your best judgment.

Table 1: Estimating Hot Water Loads Based on Number of Occupants and California Climate

	Number of Occupants in Household			
Climate Type	**1-2**	**3**	**4**	**5+**
Mountain Regions	Low / **Mod**	**Mod** / Above Avg	**Above Avg** / High	High
North Coast/ Cold Foothills	**Low** / Mod	**Mod** / Above Avg	Above Avg	Above Avg / **High**
Moderate North/Central Inland Regions, Coastal Southern CA	Low	Mod	Above Avg	Above Avg / **High**
Inland Southern California/ Hot Central Valley Regions	Low	Mod	Above Avg	**Above Avg** / High
Hot Desert Regions	Low	Mod	**Mod** / Above Avg	**Above Avg** / High

Step 3: Calculate Electric and Gas Rate Factors to Reflect Local Retail Prices

3a. Calculate Electric Rate Factor

Equation 1: (Natural gas Customers) Local Average Electric

$$Elec_{factor} = \frac{Local\ Average\ Electric\ Rate(\frac{\$}{kwh})}{\frac{\$0.10}{kWh}\ (nominal\ Electric\ Rate)}$$

3b. Calculate Gas Rate Factor

Equation 2: (Natural gas customers) Local Average Gas Rate

$$Gas_{factor} = \frac{Local\ Average\ Gas\ Rate\ (\frac{\$}{therm})}{\frac{\$1.00}{therm}\ (nominal\ Gas\ Rate)}$$

Equation 3: (Propane Customers) Local Average Propane Rate

$$Gasfactor = \frac{Local\ Average\ Propane\ Rate\ (\frac{\$}{gallon}) * \frac{gallon}{0.91\ therm}}{\frac{\$1.00}{therm}\ (nominal\ Gas\ Rate)}$$

Step 4: Calculate Base Case Annual Water Heating Cost

Identify the base case water heater type (gas storage or electric storage). For retrofit projects this is the existing water heater. For new construction this depends on local building code. Calculate Base Case annual costs (BC$) using Table 2 and the appropriate equation below.

Table 2: Nominal Annual Operating Cost vs. Load (based on $0.10/kWh and $1.00/therm)

	Low	Moderate	Above Average	High
Electric Storage	$135	$344	$486	$785
Gas Storage	$95	$190	$258	$412

Equation 4: Water Heater Annual Base Cost (Electric Storage)

Operating Cost (Table 2) x Equation 1

Equation 5: Water Heater Annual Base Cost (gas storage)

Operating Cost (Table 2) x Equation 2 (or Equation 70 for propane)

Step 5: Calculate Advanced Systems Operating Cost

5a. HPWH

Use Table 3 to determine nominal annual HPWH operating costs. Note, if the HPWH location is not in unconditioned space (e.g. in a basement or inside conditioned space), move one climate down in the table to approximate improved performance due to more favorable operating conditions (i.e. assuming a HPWH in conditioned space in a cold climate, the operating costs for a marine climate should be used for calculations). Keep in mind that an indoor HPWH will affect space heating and cooling loads; this effect has not been considered in this evaluation process.

Table 3: Nominal Annual HPWH Operating Cost (based on $0.10/kWh)

	Low	Moderate	Above Average	High
Cold/Very Cold/Subarctic	$102	$194	$290	$574
Marine	$84	$157	$230	$437
Mixed Humid	$71	$132	$191	$352
Hot/Dry/Humid, Mixed/Dry	$62	$114	$163	$295

Equation 6: Annual HPWH Operating Cost

= Operating Cost (Table 3) x Equation 1

5b. Advanced Gas Water Heaters

Using Table 4, determine projected annual advanced gas water heating cost for technologies that are being considered. Calculate actual annual gas cost for each technology using the local

Gas_{factor}. Electric usage is estimated at 80 kWh/year for all of the advanced gas technologies. Apply local $Elec_{factor}$ to determine annual electric costs.

Table 4: Nominal Advanced Gas Water Heater Operating Cost (assumes $1.00/therm)

	Low	Moderate	Above Average	High
EnergyStar < 0.70 EF	$77	$166	$231	$376
Condensing Storage	$70	$144	$197	$317
Tankless	$49	$133	$193	$329
Condensing Tankless	$41	$116	$169	$290

Equation 7: Advanced WH Annual Gas Cost

= Operating Cost (Table 4) x Equation 2 (or Equation 70 for propane)

Equation 8: Advanced WH Annual Electrical Cost

=80 kWh x $.10/kWh x Equation 1

Equation 9: Advanced WH Total Operating Cost

= Equation 7 + Equation 8

Evaluate annual operating costs for all gas water heaters of interest.

Step 6: Estimate Incremental Costs and Define Viable Options

Incremental costs for a specific technology in a specific application will vary based on many factors, especially in retrofit situations where site factors will significantly affect the implementation costs for a given technology. Equipment make and model, product pricing through existing distribution channels, plumber familiarity with the technology, and site factors (gas line upsizing, electrical circuit upgrade, venting issues, etc) are a few of the factors that will influence final project costs. Table 5 presents default incremental costs for each of the identified technologies. The costs were developed from a variety of sources including recent vendor surveys as part of Davis Energy Group's ongoing retrofit program activities, the NREL cost database, and online price quotes. It is highly recommended that current bids or refined estimates are used in lieu of the default costs, if possible.

Table 5: Default Incremental Installed Costs[1]

	New	Retrofit
HPWH	$1,000	$1,500
EnergyStar < 0.70 EF	$400	$800
Condensing Storage	$700	$1,600
Tankless	$600	$2,000
Condensing Tankless	$900	$2,300

Step 7: Calculate Projected Savings for All Alternatives

New construction and retrofit applications are deemed to have different economic drivers. For new construction, the presumption is that a positive cash flow on a fixed rate thirty year mortgage would be a favorable investment. For retrofit, a ten year simple payback is the metric for determining the cost-effectiveness of various efficiency alternatives. For simplicity the calculation does not take into account the impact of gas/electric rate escalations or mortgage tax deduction benefits, although one could perform such a calculation, if desired.

For new construction cases, go to step 7a, and for retrofit proceed to step 7b.

Step 7a: Calculate Projected Cost Effictiveness for New Construction Case

[1] Ideally use site-specific cost estimates in lieu of default values

Table 6 presents amortization factors for both 15 and 30 year fixed rate loans. Select the appropriate Amortization Factor (**AF**), with interpolation between values allowed, if needed.

Table 6: Amortization Factor (Fixed Rate Loan Assumed)

Interest Rate	Amortization Factor (30 year term)	Amortization Factor (15 year term)
3%	0.051	0.083
4%	0.057	0.089
5%	0.064	0.095
6%	0.072	0.101
7%	0.080	0.108

To compute cost effectiveness, enter Base Case **(BC)** from Step 4 in the Base Case row and **Total$** for alternative system options from Steps 5a and 5b into column A of Table 7 In Column B, subtract base case operating costs to determine annual savings (positive value in Column B).

Table 7: New Construction Annual Savings Calculation

System Type	[A] Annual Operating Cost ($)	[B] Projected Annual Savings ($)
Base Case	BC= $	n/a
HPWH	A1: $	= BC – A1 = $
EnergyStar < 0.70 EF	A2: $	= BC – A2 = $
Condensing Storage	A3: $	= BC – A3 = $
Tankless	A4: $	= BC – A4 = $
Condensing Tankless	A5: $	= BC – A5 = $

This requires the entry of information from Table 2 - Table 4 and also the existence of any local incentives that would reduce the cost of the advanced measure. A cost effectiveness ratio is calculated as shown in Column E. Any measure with a value greater than one is deemed cost-effective, with larger values indicating greater cost-effectiveness.

Table 8: New Construction Cost Effectiveness Calculation

	A	B	C	D	E
	(Table 7) Annual Savings ($)	(Table 6) Amortization Factor	(Table 5) Incremental Cost ($)	Incentives ($)	Cost Eff Ratio A/(B*(C-D))
HPWH					
EnergyStar < 0.70 EF					
Condensing Storage					
Tankless					
Condensing Tankless					

Step 7b: Calculate Projected Savings for Retrofit Case

This tool presumes a ten year simple payback as a reasonable retrofit economic criterion for assessing cost-effectiveness of competing technologies. To compute ten year savings enter **BC** from Step 4 in the Base Case row and **Total$** from Steps 5a and 5b for alternative system options into column A of Table 9. In Column B, ten year savings are calculated.

Two final factors affecting cost may come into play before completing a final determination of alternative system cost-effectiveness: incentives or tax credits and costs associated with site-level fuel switching. Local, state, and or federal incentives or tax credits for individual technologies may be available. Fuel switching costs include those associated with converting a site from electric-to-gas (in areas where gas service is new to the area) or from gas/propane to electric (where electric rates are low and HPWHs may be attractive)[2]. **Table 10** is used to compute retrofit cost effectiveness taking into account these two factors. Incentive amounts are entered into Column C and Column D is designed to include costs associated with fuel switching. Column E performs the final calculation for determination of savings for a specific technology.

[2] In this case, there will be a cost for running a 240V dedicated circuit to the HPWH.

Table 9: Calculation of Ten Year Savings

System Type	[A] Annual Operating Cost $	[B] Ten Year Projected Savings $
Base Case	BC= $	n/a
HPWH	A1: $	= 10 * (BC – A1) = $
EnergyStar < 0.70 EF	A2: $	= 10 * (BC – A2) = $
Condensing Storage	A3: $	= 10 * (BC - A3) = $
Tankless	A4: $	= 10 * (BC - A4) = $
Condensing Tankless	A5: $	= 10 * (BC - A5) = $

Table 10: Retrofit Cost Effectiveness Calculation

	A	B	C	D	E
	(Table 9) **Ten Year Savings**	(Table 5) **Est. Incr. Cost**	**Incentives**	**Fuel Switch Cost**	**Calculated Savings (A+C)-(B+D)**
HPWH					
EnergyStar < 0.70 EF					
Condensing Storage					
Tankless					
Condensing Tankless					

Compare ten year savings to incremental installation cost. If the savings are > than incremental installation cost, then the measure is deemed cost-effective over a ten year time horizon.

Appendix D: Load profiles for testing water heaters from proposed EU ecodesign regulations for water heaters

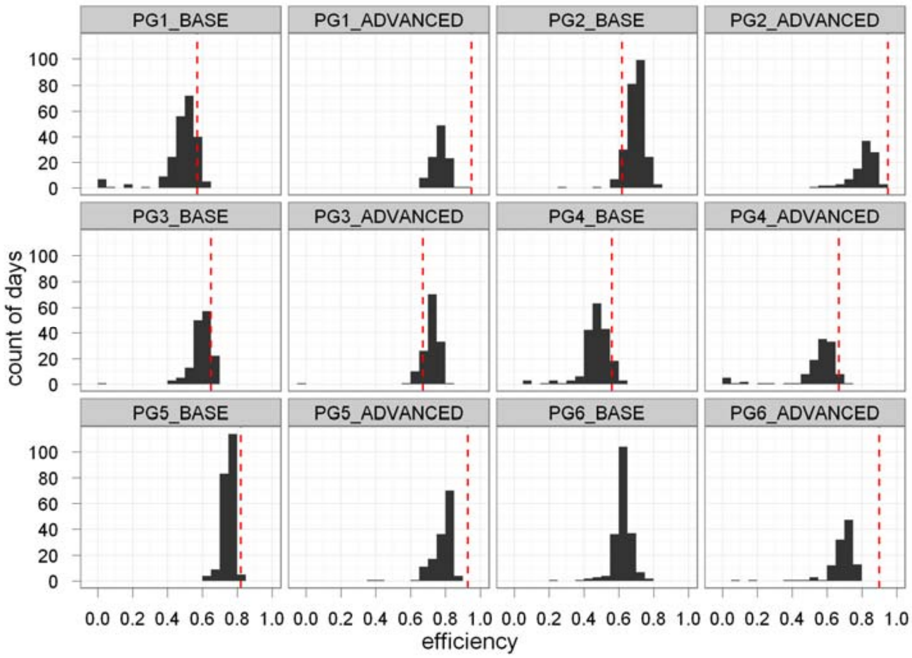
	3XS			XXS			XS			S			
	Qtap	F	Tm	Qtap	F	Tm	Qtap	F	Tm	Qtap	F	Tm	Tp
h	kWh	l/mn	ºC	kWh	l/mn	ºC	kWh	l/mn	ºC	kWh	l/mn	ºC	ºC
7:00	0.015	2	25	0.105	2	25				0.105	3	25	
7:05	0.015	2	25										
7:15	0.015	2	25										
7:26	0.015	2	25										
7:03	0.015	2	25	0.105	2	25	0.525	4	35	0.105	3	25	
7:45													
8:01													
8:05													
8:15													
8:25													
8:03				0.105	2	25				0.105	3	25	
8:45													
9:00	0.015	2	25										
9:30	0.015	2	25	0.105	2	25				0.105	3	25	
10:00													
10:30													
11:00													
11:30	0.015	2	25	0.105	2	25				0.105	3	25	
11:45	0.015	2	25	0.105	2	25				0.105	3	25	
12:00	0.015	2	25	0.105	2	25							
12:30	0.015	2	25	0.105	2	25							
12:45	0.015	2	25	0.105	2	25	0.525	4	35	0.315	4	10	55
14:30	0.015	2	25										
15:00	0.015	2	25										
15:30	0.015	2	25										
16:00	0.015	2	25										
16:30													
17:00													
18:00				0.105	2	25				0.105	3	25	
18:15				0.105	2	25				0.105	3	40	
18:30	0.015	2	25	0.105	2	25							
19:00	0.015	2	25	0.105	2	25							
19:30	0.015	2	25	0.105	2	25							
20:00				0.105	2	25							
20:30							1.05	4	35	0.42	4	10	55
20:45				0.105	2	25							
20:46													
21:00				0.105	2	25							
21:15	0.015	2	25	0.105	2	25							
21:30	0.015	2	25							0.525	5	45	
21:30	0.015	2	25	0.105	2	25							
21:45	0.015	2	25	0.105	2	25							
Qref	0.345			2.1			2.1			2.1			

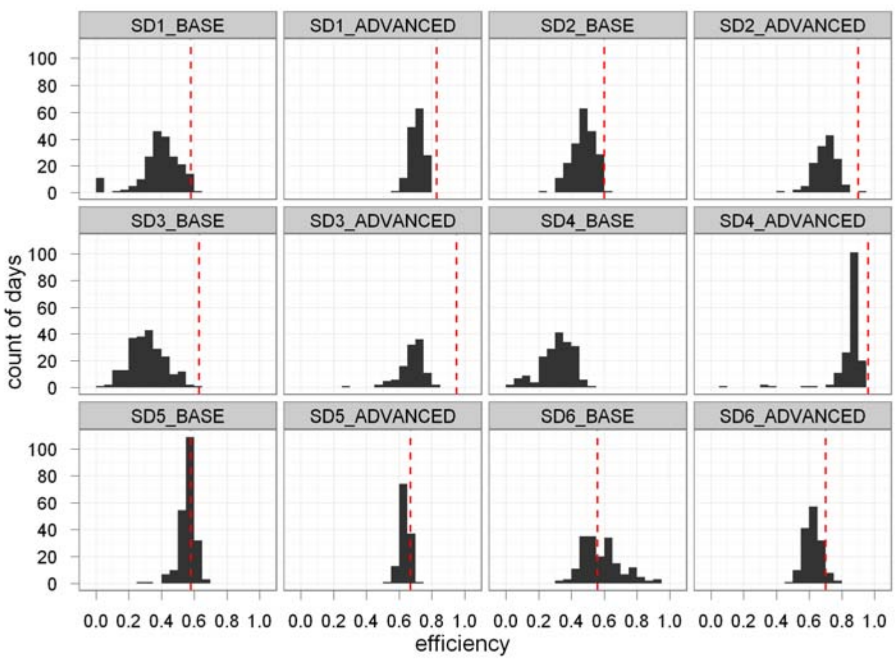
	M				L				XL			
	Qtap	F	Tm	Tp	Qtap	f	Tm	Tp	Qtap	f	Tm	Tp
h	kWh	l/mn	ºC	ºC	kWh	l/mn	ºC	ºC	kWh	l/mn	ºC	ºC
7:00	0.105	3	25		0.105	3	25		0.105	3	25	
7:05	1.400	6	40		1.400	6	40					
7:15									0.105	3	25	
7:26												
7:03	0.105	3	25		0.105	3	25					
7:45					0.105	3	25		4.420	10	10	40
8:01	0.105	3	25						0.105	3	25	
8:05					3.605	10	10	40				
8:15	0.105	3	25						0.105	3	25	
8:25					0.105	3	25					
8:03	0.105	3	25		0.105	3	25		0.105	3	25	
8:45	0.105	3	25		0.105	3	25		0.105	3	25	
9:00	0.105	3	25		0.105	3	25		0.105	3	25	
9:30	0.105	3	25		0.105	3	25		0.105	3	25	
10:00	0.105	3	25									
10:30	0.105	3	10	40	0.105	3	10	40	0.105	3	10	40
11:00	0.105	3	25						0.105	3	25	
11:30	0.105	3	25		0.105	3	25		0.105	3	25	
11:45	0.105	3	25		0.105	3	25		0.105	3	25	
12:00												
12:30												
12:45	0.315	4	10	55	0.315	4	10	55	0.735	4	10	55
14:30	0.105	3	25		0.105	3	25		0.105	3	25	
15:00	0.105	3	25									
15:30	0.105	3	25		0.105	3	25		0.105	3	25	
16:00	0.105	3	25									
16:30	0.105	3	25		0.105	3	25		0.105	3	25	
17:00	0.105	3	25									
18:00	0.105	3	25		0.105	3	25		0.105	3	25	
18:15	0.105	3	40		0.105	3	40		0.105	3	40	
18:30	0.105	3	40		0.105	3	40		0.105	3	40	
19:00	0.105	3	25		0.105	3	25		0.105	3	25	
19:30												
20:00												
20:30	0.735	4	10	55	0.735	4	10	55	0.735	4	10	55
20:45												
20:46									4.420	10	10	40
21:00					3.605	10	10	40				
21:15	0.105	3	25						0.105	3	25	
21:30	1.400	6	40		0.105	3	25		4.420	10	10	40
21:30												
21:45												
Qref	5.845				11.655				19.070			

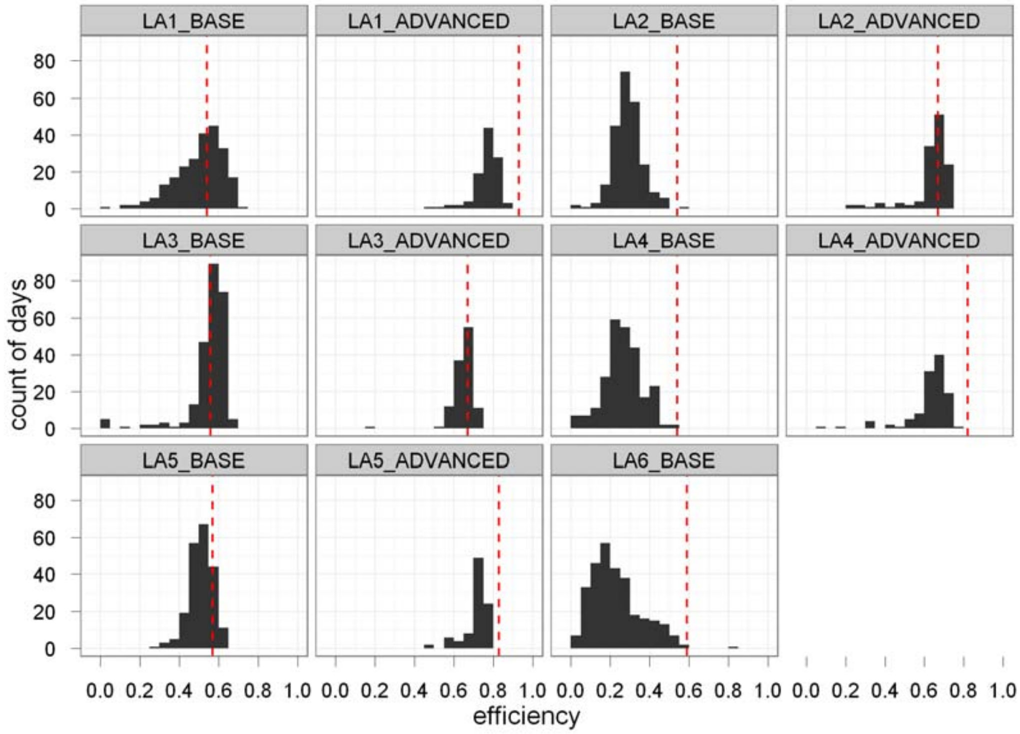
	XXL				3XL				4XL			
	Qtap	f	Tm	Tp	Qtap	f	Tm	Tp	Qtap	f	Tm	Tp
h	kWh	l/mn	ºC	ºC	kWh	l/mn	ºC	ºC	kWh	l/mn	ºC	ºC
7:00	0.105	3	25		11.2	48	40		22.4	96	40	
7:05												
7:15	1.820	6	40									
7:26	0.105	3	25									
7:03												
7:45	6.240	16	10	40								
8:01	0.105	3	25		5.04	24	25		10.08	48	25	
8:05												
8:15	0.105	3	25									
8:25												
8:03	0.105	3	25									
8:45	0.105	3	25									
9:00	0.105	3	25		1.68	24	25		3.36	48	25	
9:30	0.105	3	25									
10:00	0.105	3	25									
10:30	0.105	3	10	40	0.84	24	10	40	1.68	48	10	40
11:00	0.105	3	25									
11:30	0.105	3	25									
11:45	0.105	3	25		1.68	24	25		3.36	48	25	
12:00												
12:30												
12:45	0.735	4	10	55	2.52	32	10	55	5.04	64	10	55
14:30	0.105	3	25									
15:00	0.105	3	25									
15:30	0.105	3	25		2.52	24	25		5.04	48	25	
16:00	0.105	3	25									
16:30	0.105	3	25									
17:00	0.105	3	25									
18:00	0.105	3	25									
18:15	0.105	3	40									
18:30	0.105	3	40		3.36	24	25		6.72	48	25	
19:00	0.105	3	25									
19:30												
20:00												
20:30	0.735	4	10	55	5.88	32	10	55	11.76	64	10	55
20:45												
20:46	6.240	16	10	40								
21:00												
21:15	0.105	3	25									
21:30	6.240	16	10	40	12.04	48	40		24.08	96	40	
21:30												
21:45												
Qref	24.53				46.76				93.52			

Appendix E: DOE Energy Factors and Real World Efficiencies

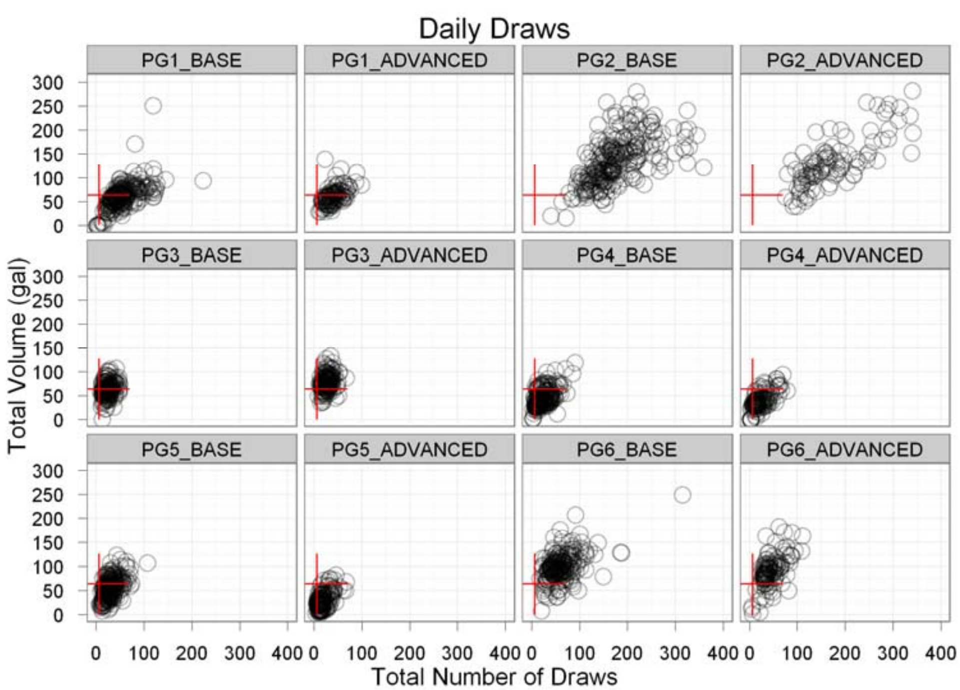
Water Heater Field Efficiency

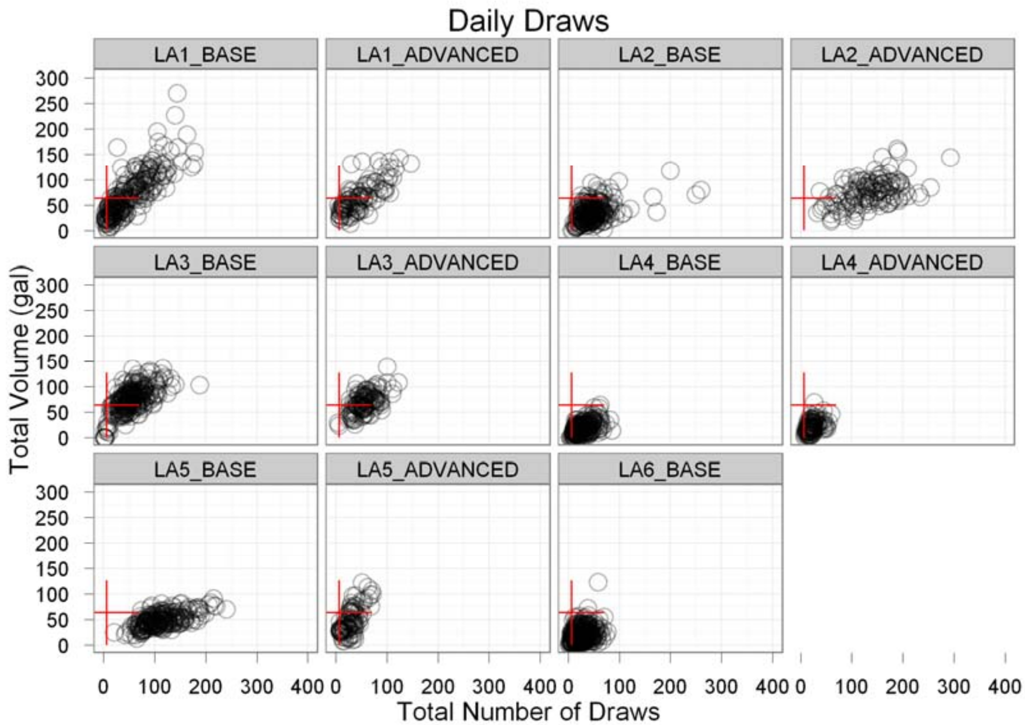


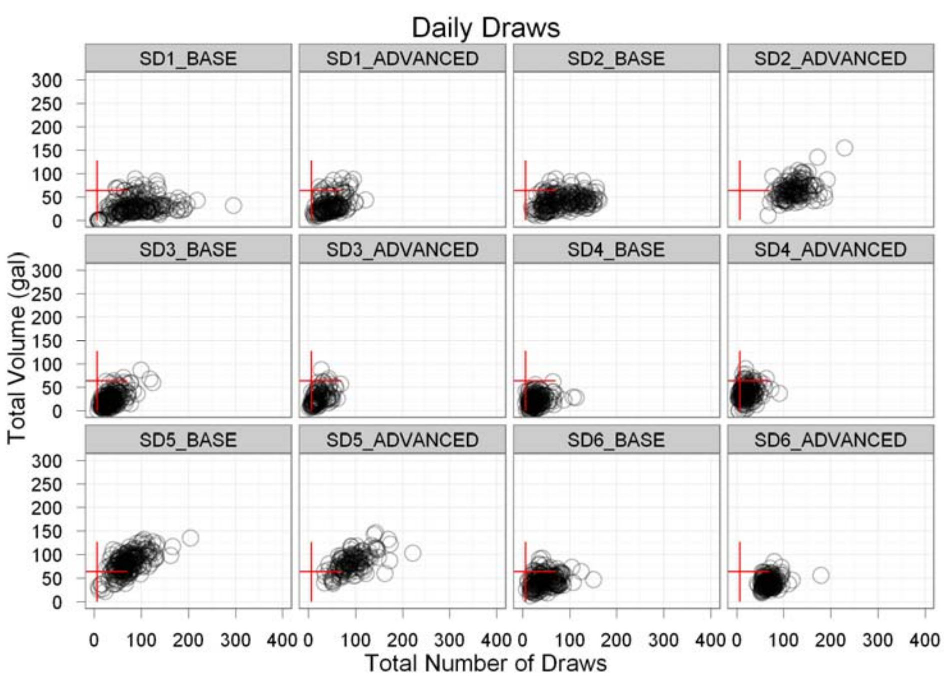




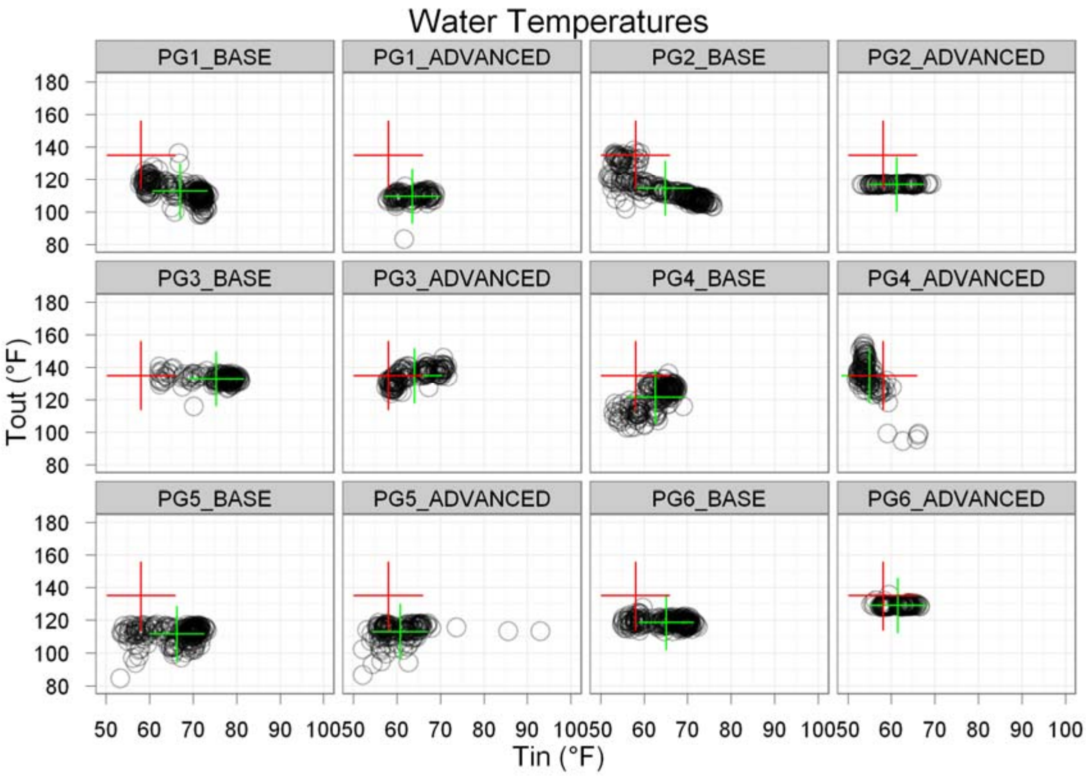
Number and Volume of Daily Hot Water Draws

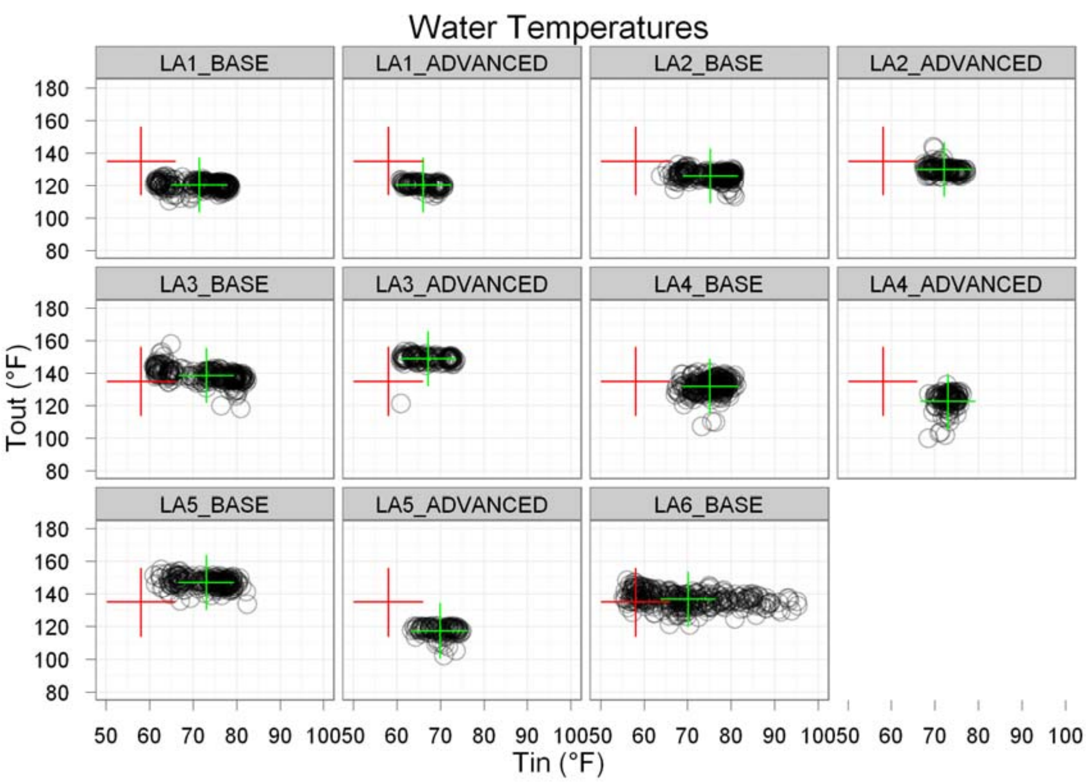


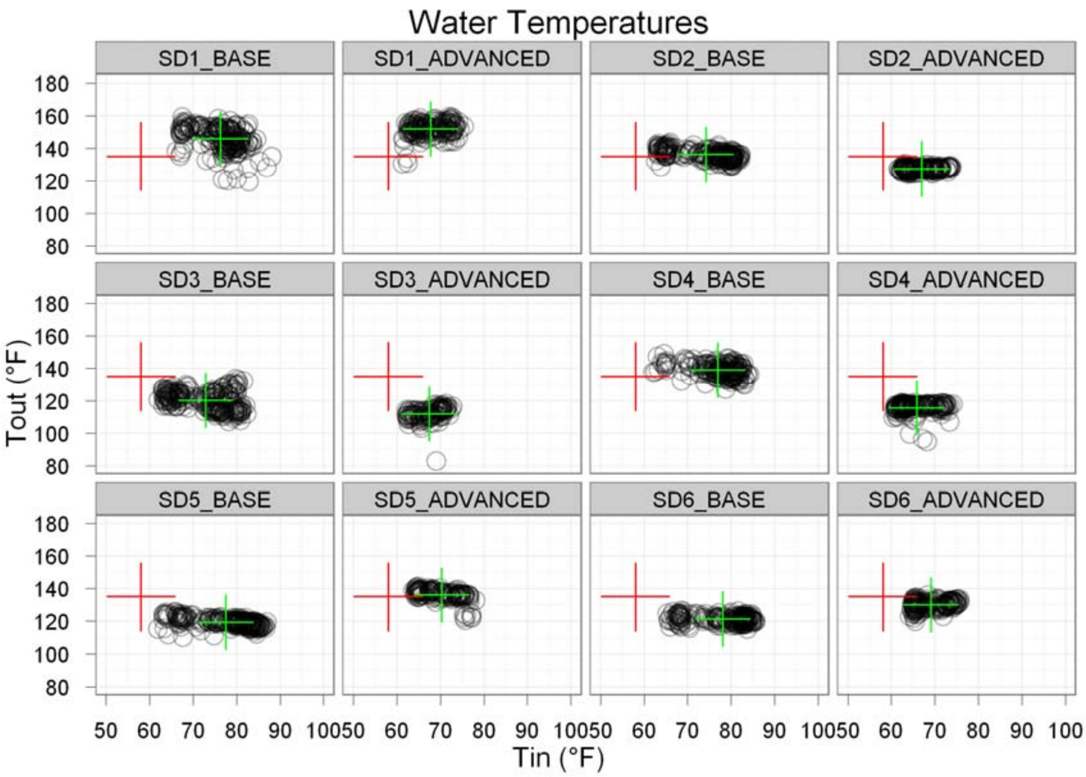

Daily Draws
LA1_BASE
LA1_ADVANCED
LA2_BASE
LA2_ADVANCED
LA3_BASE
LA3_ADVANCED
LA4_BASE
LA4_ADVANCED
LA5_BASE
LA5_ADVANCED
LA6_BASE
Total Volume (gal)
Total Number of Draws


Daily Draws
SD1_BASE
SD1_ADVANCED
SD2_BASE
SD2_ADVANCED
SD3_BASE
SD3_ADVANCED
SD4_BASE
SD4_ADVANCED
SD5_BASE
SD5_ADVANCED
SD6_BASE
SD6_ADVANCED
Total Volume (gal)
Total Number of Draws

Average Daily Inlet and Outlet Temperatures






Water Temperatures
SD1_BASE
SD1_ADVANCED
SD2_BASE
SD2_ADVANCED
SD3_BASE
SD3_ADVANCED
SD4_BASE
SD4_ADVANCED
SD5_BASE
SD5_ADVANCED
SD6_BASE
SD6_ADVANCED
Tout (°F)
Tin (°F)

Appendix F: Title 24 Improvements 2008 Residential Alternative Calculation Method

2008 Residential ACM Appendix E- Water Heating Calculation Method

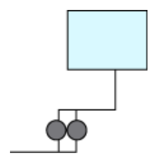
E1 Purpose and Scope

ACM RG documents the methods and assumptions used for calculating the hourly energy use for residential water heating systems for both the proposed design and the standard design. The hourly fuel and electricity energy use for water heating will be combined with hourly space heating and cooling energy use to come up with the hourly total fuel and electricity energy use to be factored by the hourly TDV energy multiplier. The calculation procedure applies to low-rise single family, low-rise multi-family, and high-rise residential.

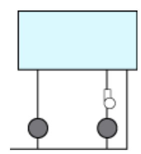
When buildings have multiple water heaters, the hourly total water heating energy use is the hourly water heating energy use summed over all water heating systems, all water heaters, and all dwelling units being modeled.

The following diagrams illustrate some of the cases that are recognized by ACM.

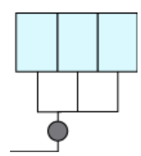
1 One distribution system with two water heaters serving a single dwelling unit.



2 Two distribution systems, each with a single water heater serving a single dwelling unit.



3 One distribution system with one water heater serving multiple dwelling units.



4 Single distribution system with multiple water heaters serving multiple units.

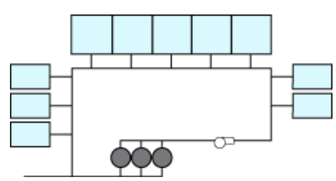


Figure 11: Cases that are recognized by ACM

The following rules apply to the calculation of water heating system energy use:

- One water heater type per system, e.g. no mix of gas and electric water heaters in the same system

- One solar credit per system.
- Any gas fired system using a temperature buffering storage tank that is electric heating must use the distribution factor for temperature buffering storage tanks provided in
-
- Table **12**.

E2 Water Heating Systems

Water heating distribution systems may serve more than one dwelling unit and may have more than one piece of water heating equipment. The energy used by a water heating system is calculated as the sum of the energy used by each individual water heater in the system. Energy used for the whole building is calculated as the sum of the energy used by each of the water heating systems. To delineate different water heating elements several indices are used.

i Used to describe an individual dwelling unit. For instance CFAi would be the conditioned floor area of the i^{th} dwelling unit. "N" is the total number of dwelling units.

j Used to refer to the number of water heaters in a system. "M" is the total number of water heaters.

k Used to refer to a water heating system or distribution system. A building can have more than one system and each system can have more than one water heater.

l Used to refer to the l^{th} unfired- or indirectly-fired storage tank in the k^{th} system. "L" is the total number of unfired- or indirectly-fired storage tanks in the k^{th} system. Temperature buffering tanks with electric heating shall not to be treated as unfired or indirectly-fired storage tanks.

E3 Hourly Adjusted Recovery Load

The hourly adjusted recovery load (HARL) can be calculated by Equation 10 through Equation 16.

Equation 10: HARL

$$HARL_k = HSEU_k \times DLM_k \times SSM_k + HRDL_k + \sum_l HJL$$

Where:

$HARL_k$ =	Hourly adjusted recovery load (Btu).	
$HSEU_k$ =	Hourly standard end use (Btu).	See Equation 11
DLM_k =	Distribution loss multiplier (unitless).	See Equation 13
SSM_k =	Solar Savings Multiplier (unitless)	See Equation 16
$HRDL_k$ =	Hourly recirculation distribution loss (Btu)	See Equation 20

HJL_l = The tank surface losses of the l^{th} unfired tank of the k^{th} system (Btu) See Equation 37

Equation 10 calculates the hourly adjusted recovery load (HARL) which is the heat content of the water delivered at the fixture. HRDL only occurs for multi-family central water heating systems and is zero for single family dwellings.

Equation 11: hourly standard end use (HSEU)

$$HSEU_k = 8.345 \times GPH_k \times \Delta T$$

Where:

$HSEU_k$ = Hourly standard end use (Btu).

GPH_k = Hourly hot water consumption (gallons)

ΔT = Temperature difference (ºF) See Equation 12

Equation 11 calculates the hourly standard end use (HSEU) for each hour at all fixtures. The heat content of the water delivered at the fixture is the draw volume in gallons (GPH) times the temperature rise ΔT (difference between the cold water inlet temperature and the hot water supply temperature) times the heat required to elevate a gallon of water 1ºF (the 8.345 constant). GPH are calculated in a manner consistent with the Standard Recovery Load values in the current water heating methodology).

Equation 12: temperature difference (ºF) between cold water inlet temperature T_{inlet} and the hot water supply temperature T_s

$$\Delta T = T_s - T_{inlet}$$

Where:

ΔT = (ºF) Temperature difference between the cold water inlet and the hot water supply

T_s =Hot water supply temperature of 135ºF.

T_{inlet} = The cold water inlet temperature (ºF) provided in Table 13

Equation 12 calculates the temperature difference (ºF) between cold water inlet temperature T_{inlet} and the hot water supply temperature T_s.

Equation 13: Distribution Loss Multiplier

$$DLM_k = 1 + (SDLM_k - 1) \times DSM_k$$

Where:

DLM_k = Distribution loss multiplier (unitless)

$SDLM_k$ = Standard distribution loss multiplier (unitless). See Equation 13 or

Equation 14

DSM_k = Distribution system multiplier (unitless) Equation RE-4 calculates the distribution loss multiplier (DLM) which combines two terms: the standard distribution loss multiplier (SDLM), which depends on the size of the dwelling unit and the number of stories, and the distribution system multiplier (DSM) listed in

Table 12.

Equation 14: Standard Distribution Loss Multiplier

$$SDLM_k = 1.064 + 0.000084 \times CFA_k$$

Where:

$SDLM_k$ = Standard distribution loss multiplier (unitless).

0.0000084 = loss per square foot (1/sq.ft.)

CFA_k = Conditioned floor area (ft^2) capped at 2500 ft^2 for all single and multi-family units.

Equation 14 calculates the standard distribution loss multiplier (SDLM) for one story dwelling units, based on CFA_k (equal to the total CFA divided by the number of water heaters per dwelling unit). Multi-family SDLM's will be calculated based on the one story equation and the average CFA for all units. CFA_k is capped at 2500 ft^2 for all single and multi-family units.

Equation 15: Standard Distribution Loss Multiplier

$$SDLM_k = 1.023 + 0.000056 \times CFA_k$$

Where

$SDLM_k$ = Standard distribution loss multiplier (unitless).

0.000056 = loss per square foot (1/sq.ft.)

CFA_k = Conditioned floor area (ft^2) capped at 2500 ft^2 for all single and multi-family units.

Equation 15 calculates the standard distribution loss multiplier (SDLM) for two and three story dwelling units, based on CFA_k (equal to the total CFA divided by the number of water heaters per dwelling unit). CFA_k is capped at 2500 ft^2 for all single and multi-family units.

Equation 16: Total water heating budget that is not provided by solar hot water heating

$$SSM_k = 1 - SSF_k$$

Where

SSM_k = the solar savings multiplier (unitless) for the k^{th} water heating system

Equation 16 determines the amount of the total water heating budget that is not provided by solar hot water heating. The value for SSF is provided from the results generated by the solar water heating calculations approved approaches for the OG-100 and OG-300 test procedure.

$HARL_k$ = Hourly adjusted recovery load (Btu).

$HSEU_k$ = Hourly standard end use (Btu). This is the amount of heat delivered at the hot water fixtures relative to the cold water inlet temperature.

$HRDL_k$ = Hourly recirculation distribution loss (Btu) is the hot water energy loss in multi-family central water heating recirculation systems (See

E4 Hourly Recirculation Distribution Loss for Central Water Heating Systems).HRDL is zero for all single family water heating systems and for multi-family systems with individual water heaters.

DLM_k = Distribution loss multiplier (unitless).

GPH_k = Hourly hot water consumption (gallons) of the k^{th} system provided in

Table 11.

T_s =Hot water supply temperature of 135ºF.

T_{inlet} = The cold water inlet temperature (ºF) provided in Table 13.

$SDLM_k$ = Standard distribution loss multiplier (unitless). This is calculated using

Equation 14 for single story dwelling units and from Equation 15 for dwelling units with two or more stories. All multi-family projects utilize

Equation 14 and the average dwelling unit CFA.

DSM_k = Distribution system multiplier (unitless) provided in

Table **12**.

CFA_k = Conditioned floor area (ft^2) capped at 2500 ft^2 for all single and multi-family units.

When a water heating system has more than one water heater, the total system load is assumed to be shared equally by each water heater. The HARL for the j^{th} water heater is then shown in the following equation.

Equation 17: Hourly Standard End Use for each Water Heater

$$HARL_j = \frac{HARL_k + \sum_{l=1}^{L} HJL_l}{NmbrWH_k}$$

where

$HARL_f$ = Hourly adjusted recovery load for the j^{th} water heater of the k^{th} system (Btu).

$HARL_k$ = Hourly adjusted total recovery load for the k^{th} system (Btu)

HJL_l = The tank surface losses of the l^{th} unfired tank of the k^{th} system (Btu)

L = The total number of unfired tanks in the k^{th} system

$NmbrWH_k$ = The number of water heaters in the k^{th} system.

When a water heating system has more than one water heater, the total system load is assumed to be shared equally by each water heater. The HARL for the j^{th} water heater is then shown in the following equation.

E3.1 Hourly Hot Water Consumption (GPH)

The average daily hot water consumption GPD for a dwelling unit is equal to 21.5 gallons/day plus an additional 14 gallons per day for each 1000 ft^2 of conditioned floor area. Consumption is about 31.3 gallons/day for a 700 ft^2 apartment and 56.5 gallons/day for a 2500 ft^2 dwelling unit. The equation for daily hot water consumption can be expressed as follows:

Equation 18: Daily Hot Water Consumption

$$GPD_i = 21.5 + 0.014 \times CFA_i$$

where

GPD_i = Average daily hot water consumption (gallons) of the i^{th} dwelling unit.

CFA_i = Conditioned floor area (ft^2) of the i^{th} dwelling unit. When actual conditioned floor area is greater than 2500 ft^2, 2500 should be used in the above equation.

The hourly water consumption GPH of the k^{th} system is calculated using the average daily hot water consumption and the hourly water consumption schedule for all dwelling units served by the system.

Equation 19: Daily Hot Water Consumption per System

$$GPH_k = \left(\sum_i GPD_i\right) \times SCH_m$$

where

GPH_k = Hourly hot water consumption (gallons) of the k[th] system.

SCH_m = Fractional daily load for hour "m" from

Table 11.

m = Hour of the day.

There are significant variations between hot water usage on weekdays and weekends, and separate schedules are used. The hourly schedules shown in

Table 11 shall be used for calculating the hourly hot water consumption. These data are used for dwelling units of all types.

Table 11: Hourly Water Heating Schedules

Hour	Weekday	Weekend
1	0.014	0.018
2	0.008	0.010
3	0.009	0.009
4	0.011	0.008
5	0.020	0.015
6	0.044	0.023
7	0.089	0.026
8	0.107	0.047
9	0.089	0.077
10	0.066	0.083
11	0.052	0.074
12	0.038	0.061
13	0.036	0.051
14	0.033	0.043
15	0.032	0.039
16	0.026	0.039
17	0.042	0.052
18	0.048	0.058
19	0.052	0.056
20	0.047	0.052
21	0.042	0.047
22	0.039	0.044
23	0.036	0.040
24	0.022	0.028
Sum	1.000	1.000

E 3.2 Distribution System Multiplier (DSM) within the Dwelling Unit

The distribution system multiplier (unitless) is an adjustment for alternative water heating distribution systems within the dwelling unit. A value of one is used for standard distribution systems defined as a "main and branch" piping system with the portion of all lines leading from the from the water heater to the kitchen fixtures are insulated to a nominal R-4. Values for alternative alternative distribution systems are given in

Table **12**.

E3.3 Cold Water Inlet Temperature

The water inlet temperature varies monthly by climate zone and is equal to the assumed ground temperature as shown in Table 13.

Table 12 Distribution System Multipliers within a Dwelling Unit with Owners

Distribution System Measure	Code	DSM
Pipe Insulation (all lines)	PIA	0.90
Uninsulated Pipe below Grade	UPBG	3.80
Insulated and Protected pipe below grade	IPBG	1.0
Point of Use	POU	0.00
Standard -Kitchen Pipe Insulation– Standard Case	STD	1.00
Standard pipes with no insulation	SNI	1.20
Parallel Piping	PP	1.00
Recirculation (no control)	RNC	4.50
Recirculation + timer control	RTm	3.00
Recirculation + temperature control	RTmp	3.70
Recirculation + timer/temperature	RTmTmp	2.50
Recirculation + demand manual control	RDmm	0.90
Recirculation + demand motion-sensor control	RDms	1.0
Temperature Buffering Tank	TBT	1.2

For eligibility criteria for distribution systems see 2008 Residential ACM Reference Residential Appendix RA4.4.

Table 13 Monthly Ground Temperature (ºF)

Climate Zone	Month 1	2	3	4	5	6	7	8	9	10	11	12
1	52.2	51.5	51.4	51.8	53.1	54.5	55.6	56.4	56.4	55.8	54.7	53.4
2	53.3	51.5	51.4	52.2	55.6	58.9	61.8	63.6	63.8	62.3	59.5	56.3
3	55.1	54.1	54.0	54.5	56.5	58.5	60.3	61.4	61.5	60.6	58.9	56.9
4	55.5	54.0	53.9	54.6	57.5	60.3	62.8	64.3	64.5	63.2	60.8	58.0
5	55.7	54.8	54.7	55.2	56.9	58.7	60.2	61.1	61.2	60.4	59.0	57.3
6	59.1	58.1	58.0	58.5	60.4	62.4	64.0	65.1	65.2	64.3	62.7	60.8
7	60.1	59.1	59.0	59.5	61.5	63.4	65.2	66.2	66.3	65.5	63.8	61.9
8	60.0	58.8	58.7	59.2	61.6	63.9	66.0	67.3	67.4	66.3	64.3	62.1
9	60.5	59.1	59.0	59.7	62.2	64.8	67.1	68.5	68.6	67.5	65.3	62.8
10	59.4	57.6	57.4	58.3	61.8	65.2	68.2	70.1	70.2	68.7	65.8	62.4
11	54.9	52.4	52.2	53.4	58.2	63.0	67.2	69.8	70.0	67.9	63.8	59.2

12	54.6	52.5	52.3	53.3	57.3	61.3	64.8	67.0	67.2	65.4	62.0	58.1
13	57.5	54.7	54.5	55.8	61.0	66.2	70.6	73.5	73.7	71.4	67.0	62.0
14	54.2	51.2	51.0	52.4	58.2	63.9	68.8	72.0	72.2	69.7	64.8	59.3
15	66.8	64.0	63.8	65.1	70.4	75.8	80.4	83.3	83.6	81.2	76.7	71.5
16	44.4	41.8	41.6	42.8	47.7	52.6	56.8	59.5	59.7	57.5	53.4	48.7

E4 Hourly Recirculation Distribution Loss for Central Water Heating Systems

The distribution losses accounted for in the distribution system multiplier (DSM) see table RE-2 are within each individual dwelling unit. Additional distribution losses occur in most multi-family dwelling units related to recirculation systems between dwelling units. These losses include losses from piping that is or could be part of a recirculation loop and branch piping to individual residential units. These losses are divided into losses to the outside air, the ground and the conditioned or semi-conditioned air within the building envelope.

Outside air includes crawl spaces, unconditioned garages, unconditioned equipment rooms, as well as actual outside air. Solar radiation gains are not included in the calculation because the impact of radiation gains is relatively minimal compared to other effects. Additionally, the differences in solar gains for the various conditions (e.g., extra insulation vs. minimum insulation) are relatively even less significant.

The ground condition includes any portion of the distribution piping that is underground, including that in or under a slab. Insulation in contact with the ground must meet all the requirements of Section 150 (j), Part 6, of Title 24.

The losses to conditioned or semi-conditioned air include losses from any distribution system piping that is in an attic space, within walls (interior, exterior or between conditioned and unconditioned spaces), within chases on the interior of the building, or within horizontal spaces between or above conditioned spaces. It does not include the pipes within the residence. The distribution piping stops at the point where it first meets the boundaries of the dwelling unit.

These losses are added to the load accounted for in the hourly adjusted recovery load HARL, according to Equation 10 and calculated in the following equation.

Equation 20: hourly adjusted recovery load

$$HRDL_k = NL_{OA} \times UA_{OA} \times (T_s - T_{OA}) + NL_{UG} \times UA_{UG} \times (T_s - T_G) + NL_P \times UA_P$$

where

$HRDL_k$ = Hourly recirculation distribution loss (Million Btu).

T_s = Hot water supply temperature of 135°F.

T_{OA} = Hourly dry-bulb temperature of outside air (°F).

T_G = Hourly ground temperature (°F) assumed constant for each month

Table 13.

NL_{OA} = Normalized load coefficient for outside air term. See Equation 21

NL_{UG} = Normalized load coefficient for underground term. See Equation 22

NL_{P} = Normalized load coefficient for conditioned or semi-conditioned term. See Equation 23

UA_{OA} = Heat loss rate of circulation pipe exposed to outside air (Btu/hr-°F). See Equation 28

UA_{UG} = Heat loss rate of circulation pipe buried under ground (Btu/hr-°F)). See Equation 28 and

Equation **29**

UA_{P} = Heat loss rate of circulation pipe in conditioned or semi-conditioned space (Btu/hr-°F).). See Equation 28 and

Equation **29**

MSC = 0.80 Multiplier - Adjustment factor for installation of monitoring equipment or demand modulated equipment. See eligibility criteria in 2008 Residential ACM Reference Residential Appendix RA4.4.9.2 for installation requirements

The terms UA_{OA}, UA_{UG}, and UA_{P} represent the conductive area and heat loss rate for the three pipe locations. In each case the UA is a function of the pipe length, pipe diameter and pipe insulation. The program user will need to specify pipe length in each of the three locations, and specify the insulation as being either minimum (as specified in Section 150 (j), Part 6, of Title 24), or extra. Length and corresponding insulation R-value takeoffs are required for piping in each of the three locations (outdoors, underground, and conditioned or semi-conditioned space). Pipe heat loss rates (UA_{OA}, UA_{UG}, and UA_{P}) are then calculated for use in Equation 20.

The normalized load coefficients, NL_{OA}, NL_{UG}, and NL_{P}, are climate zone specific multipliers for the pipe losses to the outside air, underground and conditioned or semi-conditioned space, respectively. They are calculated according to the following equations:

Equation 21: Normalized Load Coefficient

$$NL_{OA} = \frac{C_{OA1} \times \exp\left(\frac{C_{OA2} \times UA_{OA}}{GPD_k}\right)}{WHDH_{OA}}$$

Equation 22: Normalized Load Coefficient

$$NL_{UG} = \frac{C_{UG1} \times \exp\left(\frac{C_{UG2} \times UA_{UG}}{GPD_k}\right)}{WHDH_{UG}}$$

Equation 23: Normalized Load Coefficient

$$NL_P = \frac{C_{P1} \times \exp\left(\frac{C_{P2} \times UA_P}{GPD_k}\right)}{8760}$$

where

GPD_k = The hot water consumption per day for the k^th system. It is the sum of hot water consumption per day for all dwelling units served by the k^th system.

$WHDH_{OA}$ = Water heating degree hours based on outside air temperature (hr-°F).

$WHDH_{UG}$ = Water heating degree hours based on ground temperature (hr-°F).

C_{OA1}, C_{OA2} = Coefficients for outside air pipe loss term.

C_{UG1}, C_{UG2} = Coefficients for underground pipe loss term.

C_{P1}, C_{P2} = coefficients for conditioned or semi-conditioned space pipe loss term.

Coefficients of C_{OA}, C_{UG}, and C_P vary by climate zones and control schemes of the circulation system. Table 14 lists values of these coefficients.

Table 14 Coefficients of C_{OA}, C_{UG} and C_P

Climate Zone	No Controls						Timer Controls					
	COA1	COA2	CUG1	CUG2	CP1	CP2	COA1	COA2	CUG1	CUG2	CP1	CP2
1	0.8933	-0.694	0.8922	-1.346	0.6259	-1.673	0.8658	-2.336	0.793	-2.062	0.6344	-4.475
2	0.854	-0.71	0.8524	-1.348	0.6433	-1.383	0.8269	-2.456	0.7572	-2.056	0.6529	-4.138
3	0.8524	-0.709	0.851	-1.355	0.6826	-1.464	0.8252	-2.37	0.7553	-2.049	0.6927	-4.438
4	0.8349	-0.688	0.8345	-1.343	0.6502	-0.706	0.8096	-2.433	0.7427	-2.071	0.667	-3.759
5	0.8494	-0.706	0.8476	-1.341	0.6873	-1.076	0.8218	-2.409	0.7536	-2.061	0.6922	-3.979
6	0.8095	-0.704	0.808	-1.341	0.7356	-1.697	0.7836	-2.367	0.718	-2.059	0.7341	-4.512
7	0.796	-0.673	0.7964	-1.349	0.735	-1.581	0.7734	-2.395	0.7082	-2.064	0.7416	-4.579
8	0.7941	-0.704	0.7925	-1.341	0.7321	-1.471	0.7683	-2.414	0.7049	-2.064	0.7333	-4.318
9	0.7853	-0.707	0.7843	-1.352	0.7208	-1.212	0.7599	-2.447	0.6971	-2.064	0.7248	-4.141
10	0.7854	-0.714	0.7843	-1.352	0.7193	-1.273	0.7595	-2.5	0.6971	-2.067	0.7188	-4.041
11	0.8137	-0.69	0.8139	-1.35	0.6149	-1.22	0.788	-2.443	0.7228	-2.051	0.6315	-4.306
12	0.8283	-0.685	0.8286	-1.349	0.6001	-0.323	0.8029	-2.451	0.7367	-2.061	0.621	-3.493
13	0.7818	-0.705	0.7813	-1.352	0.6699	-1.541	0.7564	-2.465	0.6937	-2.052	0.6752	-4.305
14	0.8094	-0.706	0.809	-1.351	0.6424	-0.866	0.784	-2.49	0.7187	-2.059	0.6515	-3.588
15	0.6759	-0.692	0.6764	-1.348	0.7514	-1.383	0.6535	-2.552	0.601	-2.061	0.7493	-4.182
16	0.9297	-0.701	0.929	-1.352	0.5231	-1.519	0.9007	-2.401	0.825	-2.053	0.5437	-4.423

Table 14 provides coefficients for recirculation systems where the pumps are always on and coefficients for recirculation systems that are shut off during hours 1 through 5, and hours 23 and 24 (from 10p.m. to 5a.m.). Except for systems serving only a very small number of dwelling units, there is no set of coefficients provided for the case where the circulation system does not rely on a recirculation pump. Such a system would be unlikely to supply hot water within parameters acceptable to tenants. It can be assumed that any distribution systems for supplying hot water from a central boiler or water heater require a recirculation pump and one would be supplied retroactively if not initially. For central hot water systems serving six or fewer dwelling units which have (1) less than 25' of distribution piping outdoors; (2) zero distribution piping underground; (3) no recirculation pump; and (4) insulation on distribution piping that meets the requirements of Section 150 (j) of Title 24, Part 6, the distribution system in the Standard Design will assume a pump with timer controls.

$WHDH_{OA}$ is the sum of the differences between the temperature of the supply hot water (135˚F) and the hourly outdoor temperature for all 8760 hours of the year. This term varies by climate zone. The values for this term are listed in

Table 15 below. The equation uses the hourly outdoor temperatures from the weather files incorporated in the CEC approved programs.

$WHDH_{UG}$ is the sum of the differences between the supply hot water temperature (135˚F) and the hourly ground temperature for all 8760 hours of the year. This term varies by climate zone. The appropriate values for this term are listed in

Table 15 below. The equation uses the ground temperatures from the weather files incorporated in the CEC approved programs, which are assumed to be stable on a monthly basis.

Table 15 Water Heating Degree Hours for Outside Air and Underground

Climate Zone	$WHDH_{OA}$ (hr-°F)	$WHDH_{UG}$ (hr-°F)
1	712810	710306
2	680634	678425
3	679350	677026
4	666823	664459
5	677373	674935
6	645603	643236
7	636342	633811
8	633244	630782
9	626251	623822
10	625938	623741
11	649661	647770
12	661719	659676
13	623482	621526
14	645367	643517
15	539736	537782
16	741372	739378

UA terms are calculated using inputs provided by the user and base assumptions about the pipe diameter: The user inputs are:

1. Pipe length in each of the three locations.
2. Insulation R value of the pipe in each location.
3. Number of stories above grade.
4. Number of apartment units.

The total length of the circulation pipe is calculated, along with the fraction in each location (PF_{OA}, PF_{UG} and PF_{P}). The square feet of surface area is calculated according to the following equation:

Equation 24: Surface Area of the Circulation Piping

$$SF_{total} = LF_{total} \times Dia \times \pi$$

where

SF_{Total} = The total surface area of the circulation piping, square feet.

LF_{Total} = The total lineal feet of all circulation piping, feet

π = Pi (ratio of circle's circumference to its diameter), 3.1416

Equation 25: Dia average diameter of hot water piping

$$Dia = 0.045 \times \left(\frac{LF_{Total}}{\Delta P}\right)^{0.21} \times (AptGPM)^{0.37} \times \frac{(NumApts)^{0.37}}{1.37}$$

The terms of the above equation are described below. The total system pressure drop, ΔP, given in psf is calculated in Equation 26: total system pressure drop

Equation 26: total system pressure drop

$$\Delta P = \left[P_{meter} - 4.3 \times (NumStories - 1) - 15\right] \times 144$$

where

P_{meter} = Water system supply pressure, (60 psig by assumption).

NumStories = Number of stories above grade, (but enter "4" if more than 4 stories).

Equation 27

$$AptGPM = \frac{1.765 \times (12 \times NumApts)^{0.687}}{NumApts}$$

NumApts = Number of apartments in the building served by the hot water system, apts

The UA for each of the three locations is derived as a function of the fraction of the total pipe in that location times a factor that represents the conductivity of the standard (minimum) insulation or the "extra" insulation condition. The following two equations provide the alternate equations for the two insulation cases. The factors do not vary by location so the equations for the other two locations are of exactly the same form, varying only by the fraction of pipe in that location.

The benefits of additional insulation shall be calculated as required in Section 150 (j) of Title 24. The insulation value of the ground and of protective coverings may not be used for achieving the minimum insulation values required by Section 150 (j). To qualify as extra insulation, the insulation must be at least 1/2" thicker than the insulation required by Section 150 (j).

Equation 28: For extra insulation for the standard design:

$$UA_i = SF_{Total} \times PF_i \times \left(\frac{k}{Radius \times Ln\left(\frac{Radius + Thick + 0.5}{Radius}\right)} \right)$$

Equation 29: For minimum insulation:

$$UA_i = SF_{Total} \times PF_i \times \left(\frac{k}{Radius \times Ln\left(\frac{Radius + Thick}{Radius}\right)} \right)$$

where

i = Subscript indicating pipe location OA = outside, UG = underground, P = conditioned or semi-conditioned space

PF_i = Pipe fraction in i^{th} location, no units

k = Insulation conductivity, (assumed 0.25 Btu inch/h·sf·°F)

Radius=Average pipe radius in inches, (Radius = Dia x 12 / 2), inches

Thick = Base case insulation thickness, Thick = 1 if average pipe radius is less than or equal to 2";Thick = 1.5 if radius is greater than 2", inches

E5 High Rise Residential Buildings, Hotels and Motels

Simulations for high rise residential buildings, hotels and motels shall follow all the rules for central or individual water heating with the following exceptions.

For central systems which do not use recirculation but use electric trace heaters the program shall assume equivalency between the recirculation system and the electric trace heaters.

For individual water heater systems which use electric trace heating instead of gas the program shall assume equivalency.

E6 Energy Use of Individual Water Heaters

Once the hourly adjusted recovery load is determined for each water heater, the energy use for each water heater is calculated as described below.

E6.1 Small[3] Gas, Oil, or Electric Storage[4] and Heat Pump Water Heaters

The hourly energy use of storage gas, storage electric and heat pump water heaters is given by the following equation.

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[3] "Small water heater" means a water heater that is a gas storage water heater with an input of 75,000 Btu per hour or less, an oil storage water heater with an input of 105,000 Btu per hour or less, an electric storage water heater with an input of 12 kW or less, or a heat pump water heater rated at 24 amps or less.

[4] "Small storage water heater" means a water heater that is a gas storage water heater with an input of 75,000 Btu per hour or less, an oil storage water heater with an input of 105,000 Btu per hour or less, or an electric storage water heater with an input of 12 kW. A small water heater includes a heat pump water heater rated at 24 amps or less.

Equation 30: Hourly Energy Use of the Water Heater

$$WHEU_j = \left[\frac{HARL_j \times HPAF_j}{LDEF_j} \right]$$

where

$WHEU_j$ = Hourly energy use of the water heater (Btu for fuel or kWh for electric), adjusted for tank insulation.

$HARL_j$ = Hourly adjusted recovery load (Btu).

$HPAF_j$ = Heat pump adjustment factor from the table below based on climate zone. This value is one for storage gas, storage oil and storage electric water heaters.

Table 16 Heat Pump Adjustment Factors

Climate Zone	Heat Pump Adjustment Factor	Climate Zone	Heat Pump Adjustment Factor
1	1.040	9	0.920
2	0.990	10	0.920
3	0.990	11	0.920
4	1.070	12	1.070
5	1.070	13	0.920
6	0.920	14	1.040
7	0.920	15	0.920
8	0.920	16	1.500

$LDEF_j$ = The hourly load dependent energy factor (LDEF) is given by the following equation. This equation adjusts the standard EF for different load conditions.

Equation 31: Hourly Load Dependent Energy Factor

$$LDEF_j = e \times \left(\ln\left(\frac{HARL_j \times 24}{1000} \right) \left(a \times EF_j + b \right) + \left(c \times EF_j + d \right) \right)$$

where

a,b,c,d,e = Coefficients from the table below based on the water heater type.

Table 17 LDEF Coefficients

Coefficient	Storage Gas	Storage Electric	Heat Pump
a	-0.098311	-0.91263	0.44189
b	0.240182	0.94278	-0.28361
c	1.356491	4.31687	-0.71673
d	-0.872446	-3.42732	1.13480
e	0.946	0.976	0.947

Note 1: EF for storage gas water heaters under 20 gallons must be assumed to be 0.58 unless the manufacturer has voluntarily reported an actual EF to the California Energy Commission. As of April 2003, manufacturers of this equipment are no longer required to do so.

Note 2: LDEF shall not reduce the energy consumption of the proposed water heating system.

EFj = Energy factor of the water heater (unitless). This is based on the DOE test procedure.

E6.2 Small Gas or Oil Instantaneous[5]

The hourly energy use for instantaneous gas or oil water heaters is given by the following equations.

Equation 32: Hourly Energy Use gas or oil water heaters

$$WHEU_j = \left(\frac{HARL_j}{EF_j * 0.92} \right)$$

where

$WHEU_j$ = Hourly fuel energy use of the water heater (Btu).

$HARL_j$ = Hourly adjusted recovery load.

EF_j = Energy factor from the DOE test procedure (unitless). This is taken from manufacturers' literature or from the CEC Appliance Database.

5 "Instantaneous water heater" means a water heater that has an input rating of at least 4,000 Btu per hour per gallon of stored water. Small instantaneous water heaters include: gas instantaneous water heaters with an input of 200,000 Btu per hour or less, oil instantaneous water heaters with an input of 210,000 Btu 1602 per hour or less, and electric instantaneous water heaters with an input of 12 kW or less.

0.92 = Efficiency adjustment factor

Note: Small gas or oil instantaneous water heaters can be used in conjunction with demand recirculation. No other recirculation systems may be used.

E6.3 Small Electric Instantaneous

The hourly energy use for instantaneous electric water heaters is given by the following equation.

Equation 33: Hourly Energy Use for Instantaneous Electric Water Heaters

$$WHEU_{j,electric} = \frac{HARL_j}{EF_j * 0.92}$$

where

$WHEU_{j,\ elec}$ = Hourly electricity energy use of the water heater (kWh).

$HARL_j$ = Hourly adjusted recovery load.

EF_j = Energy factor from DOE test procedure (unitless). EF is adjusted for electricity by multiplying 1000* TDV mulitiplier.

0.92 = Adjustment factor to adjust for overall performance.

E6.4 Large[6] Gas or Oil Storage

Energy use for large storage gas is determined by the following equations. Note: large storage gas water heaters are defined as any gas storage water heater with a minimum input rate of 75,000 Btu/h.

Equation 34: Energy use for large storage gas

$$WHEU_j = \left[\frac{HARL_j}{EFF_j} + SBL \right]$$

where

$WHEU_j$ = Hourly fuel energy use of the water heater (Btu), adjusted for tank insulation.

[6] "Large water heater" means a water heater that is not a small water heater.

$HARL_j$ = Hourly adjusted recovery load. For independent hot water storage tank(s) substitute $HARL_j$ from Section E3.

SBL = Total Standby Loss. Obtain from CEC Appliance Database or from manufacturer literature. This value includes tank losses and pilot energy. If standby is not reported as a value, but as a percent, then standby value shall be calculated by multiplying the input by the percent listed in the CEC Appliance Database.

EFF_j = Efficiency (fraction, not %). Obtained from CEC Appliance Database or from manufacturer's literature. These products may be rated as a recovery efficiency, thermal efficiency or AFUE.

E6.5 Large Instantaneous, Indirect Gas and Hot Water Supply Boilers[7]

Energy use for these types of water heaters is given by the following equation.

Equation 35: Energy use Large Instantaneous, Indirect Gas and Hot Water Supply Boilers

$$WHEU_j = \left[\frac{HARL_j}{EFF_j \times 0.92} + PILOT_j\right]$$

where

$WHEU_j$ = Hourly fuel energy use of the water heater (Btu), adjusted for tank insulation.

$HARL_j$ = Hourly adjusted recovery load. For independent hot water storage tank(s) substitute $HARL_j$ from Section 0.

HJL_j = Hourly jacket loss (Btu/h) for tank rated with the water heater. To account for independent hot water storage tanks substitute $HARL_j$ (from Section E6.7 Jacket Loss) for $HARL_j$ storage tanks

EFF_j = Efficiency (fraction, not %). To be taken from CEC Appliance Database or from manufacturers literature. These products may be rated as a recovery efficiency, thermal efficiency or AFUE.

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7 "Hot water supply boiler" means an appliance for supplying hot water for purposes other than space heating or pool heating.

EAF_j = Efficiency adjustment factor (unitless).

$PILOT_j$ = Pilot light energy (Btu/h) for large instantaneous. For large instantaneous water heaters, and hot water supply boilers with efficiency less than 89 percent assume the default is 750 Btu/hr if no information is provided in manufacturer's literature or CEC Appliance Database.

0.92 = Adjustment factor used when system is not supplying a storage system.

E6.6 Large Electric Storage

Energy use for large storage electric water heaters is given by the following equation.

Equation 36: Energy use for large storage electric water heaters

$$WHEU_{j,elec} = \left[\frac{HARL_j}{EFF\,\bar{j}}\right] + SBL$$

where

$WHEU_{j,\,elec}$ = Hourly electricity energy use of the water heater (kWh).

EFF_j = Efficiency (fraction, not %). To be taken from CEC Appliance Database or from manufacturers literature. These products may be rated as a recovery efficiency, thermal efficiency or AFUE.

$HARL_j$ = Hourly adjusted recovery load.

SBL = Total Standby Loss. Obtain from CEC Appliance Database or from manufacturer literature. If standby is reported as a percent then the standby shall be determined by taking a percent of the equipment input rating times 3413. If no standby value is reported the standby shall be assumed to be 1 percent of the equipment input rating * 3413..

E6.7 Jacket Loss

The hourly jacket loss for the l^{th} unfired tank or indirectly fired storage tank in the k^{th} system is calculated as

Equation 37: hourly jacket loss for the l^{th} unfired tank

$$HJL_l = \frac{TSA_l \times \Delta TS}{RTI_l + REI_l} + FTL_l$$

Where

HJL_l = The tank surface losses of the l^{th} unfired tank of the k^{th} system

TSA_l = Tank surface area (ft^2).

ΔTS = Temperature difference between ambient surrounding water heater and hot water supply temperature (ºF). Hot water supply temperature shall be 135ºF. For water heaters located inside conditioned space use 75ºF for the ambient temperature. For water heaters located in outside conditions use hourly dry bulb temperature ambient.

FTL_l = Fitting losses. This is a constant 61.4 Btu/h.

REI_l = R-value of exterior insulating wrap. No less than R-12 is required.

RTI_l = R-value of insulation internal to water heater. Assume 0 without documentation.

E6.8 Tank Surface Area

Tank surface area (TSA) is used to calculate the hourly jacket loss (HJL) for large storage gas, indirect gas water heaters, and large storage electric water heaters. TSA is given in the following equation as a function of the tank volume.

Equation 38: Tank Surface Area

$$TSA_j = e \times \left(f \times VOL_j^{0.33} + g\right)^2$$

where

VOL_j = Tank capacity (gallons).

e, f, g = Coefficients given in the following table.

Table 18 Coefficients for Calculating Tank Surface Areas

Coefficient	Storage Gas	Large Storage Gas and Indirect Gas	Storage Electric and Heat Pumps
E	0.00793	0.01130	0.01010
F	15.67	11.8	11.8
G	1.9	5.0	5.0

E6.9 Electricity Use for Circulation Pumping

For single-family recirculation systems, hourly pumping energy is fixed as shown in following table.

Table 19 Single Family Recirculation Energy Use (kWh) by Hour **of Day**

Hour	Uncontrolled Recirculation	Timer Control	Temperature Control	Timer/Temp Control	Demand Recirculation
1	0.040	0	0.0061	0	0.0010
2	0.040	0	0.0061	0	0.0005
3	0.040	0	0.0061	0	0.0006
4	0.040	0	0.0061	0	0.0006
5	0.040	0	0.0061	0	0.0012
6	0.040	0	0.0061	0	0.0024
7	0.040	0.040	0.0061	0.0061	0.0045
8	0.040	0.040	0.0061	0.0061	0.0057
9	0.040	0.040	0.0061	0.0061	0.0054
10	0.040	0.040	0.0061	0.0061	0.0045
11	0.040	0.040	0.0061	0.0061	0.0037
12	0.040	0.040	0.0061	0.0061	0.0028
13	0.040	0.040	0.0061	0.0061	0.0025
14	0.040	0.040	0.0061	0.0061	0.0023
15	0.040	0.040	0.0061	0.0061	0.0021
16	0.040	0.040	0.0061	0.0061	0.0019
17	0.040	0.040	0.0061	0.0061	0.0028
18	0.040	0.040	0.0061	0.0061	0.0032
19	0.040	0.040	0.0061	0.0061	0.0033
20	0.040	0.040	0.0061	0.0061	0.0031
21	0.040	0.040	0.0061	0.0061	0.0027
22	0.040	0.040	0.0061	0.0061	0.0025
23	0.040	0	0.0061	0	0.0023
24	0.040	0	0.0061	0	0.0015
Annual Total	350	234	53	35	23

Multi-family recirculation systems may have vastly different pump sizes and is therefore calculated calculated based on the installed pump size. The hourly electricity use for pumping (HEUP) water in water in the circulation loop can be calculated by the hourly pumping schedule and the power of the of the pump motor as in

Equation **39**.

Equation 39**: hourly electricity use for pumping**

$$HEUP_k = \frac{0.746 \times PUMP_k \times SCH_{k,m,}}{\eta_k}$$

where

$HEUP_k$ = Hourly electricity use for the circulation pump (kWh).

$PUMP_k$ = Pump brake horsepower (bhp).

η_k = Pump motor efficiency.

$SCH_{k,m}$ = Operating schedule of the circulation pump. For 24-hour operation (no controls), the value is always 1. For timer controls, the value is 1 when pump is on and 0 otherwise. The pump is assumed off from 10 p.m. to 5 a.m. and on for the remaining hours.

E5.10 Prorating Energy Use in Multi-Family Buildings

For central water heating systems, the energy use is calculated at the system level, not at the dwelling unit level. When it is necessary to allocate energy use to individual dwelling units for home energy ratings or other purposes, the procedure in this section may be used.

The fraction of the energy that is allocated to an individual dwelling unit is the ratio of the gallons-per-day load for that dwelling unit to the gallons-per-day estimate for the whole building. This fraction is shown in Equation 40.

.

Equation 40: fraction of the energy that is allocated to an individual dwelling

$$\text{Fraction}_I = \frac{\text{GPD}_I}{\left(\sum_{I}^{\text{NmbrDU}} \text{GPD}_i\right)}$$

where

Fraction_i = Fraction of water heating energy allocated to the i^{th} dwelling unit.

GPD_i = Gallons per day of consumption for the i^{th} dwelling unit. See Equation 18.

Appendix G: Laboratory Tests Instrumentation Used

Table 20: Instrumentation Used for Tankless Water Heater Testing at GTI

Measured Media	Quantity/Units	Measurement Point	Instrument Type	Manufacturer, Model	Accuracy
Water	Temperature, °F	Inlet and Outlet	Ultra Precise Fast Response RTD – 1/8" dia	Omega	±0.18 °F
	Pressure, psi	Water Main Pressure	Mechanical Differential Pressure Gauge	Miljoco	± 1%
	Flow, gpm	Water Heater Outlet	In-line turbine low flow meter	Seametrics	330 pulses/gallon ± 1.0% of full scale (18 gpm)
Air	Temperature, °F	Ambient, Laboratory Ambient, Gas Analysis Room	Thermocouple	Omega, J-Type	± 0.75%
	Relative Humidity, %RH	Ambient, Laboratory Ambient, Gas Analysis Room	Thin-film capacitance probe	Vaisala HUMICAP	±1.7 %RH
Natural Gas	Temperature, °F	Fuel Inlet	Thermocouple	Omega, J-Type	± 0.75%
	Volume Consumed, cu. ft.	Fuel Inlet	Mass Flow Meter	Sierra, Smart Trak Model 100, mid range	± 1.0% of full-scale (350 CFH) 0.3 s time constant
			Diaphragm Gas Meter	METRIS, 250	20 pulses/cu. ft.
	Pressure, " W.C.	At Gas Valve Manifold	Intrinsically Safe Differential Pressure (ISDP) Transmitter	Dwyer	± 0.5%
	Fuel Speciation & HHV	Batch sample onsite	GTI Analytical Laboratory	Varian 350 gas chromatograph	± 3.0 Btu/scf
Electrici	Electrical Energy	Total Power	Wattnode™ kWh	Continental	±0.5%

ty	Consumed	Consumption	Transducer	Control Systems	
Flue Gases	Temperature, °F	Flue Outlet	Thermocouple	Omega, J-Type	± 0.75%
	CO, CO2, O2, NO, NO_2		Gas Analysis Rack	Various	± 1% (as calibrated)
Data Acquisition Hardware/Software			Compact FieldPoint™ hardware and LabVIEW Software™	National Instruments	n/a

Table 21: Instrumentation Used for Storage Water Heater Testing at PG&E

Measured Media	Quantity/Units	Measurement Point	Instrument Type	Manufacturer, Model	Accuracy
Water	Temperature, °F	Inlet and Outlet	Ultra Precise RTD – 1/4” dia	Rosemount 78 Series	± 0.15°C (intrinsic) Calibrated against Fluke-Hart Scientific 1502A (± 0.006-0.009°C)
		Storage tank array (6 per tank)	Thermocouple	Therm-X wire, T-Type	± 1.2°F
	Pressure, psi	Gauge Pressure Transmitter	Rosemount 3051C	Gauge Pressure Transmitter	± 0.065% of span (0-200 PSI)
	Flow, gpm	Manifold from all Water Heaters	Coriolis Mass Flow Meter	Micromotion R050S	400 pulses/pound ± 0.5% of rate
		Water Heater Inlet	In-line turbine low flow meter	Omega FTB4707	330 pulses/gallon ± 1.0% of full scale (18 gpm)
Air	Temperature, °F	Ambient, Laboratory (3)	Ultra Precise RTD – 1/4” dia	Rosemount 68 Series	± 0.15°C (intrinsic) Calibrated against Fluke-Hart Scientific 1502A (± 0.006-0.009°C)
	Relative Humidity, %RH	Ambient, Laboratory	Thin-film resistance probe	General Eastern MRH-1-V-OA	± 2 %RH
	Pressure, PSIA	Barometric	Electronic barometer	Qualimetrics (Novalynx) 7105-A	± 3 mB (600-1100 mB Range)
Natural Gas	Temperature, °F	Fuel Inlet	Ultra Precise RTD – 1/4” dia	Rosemount 68 Series	± 0.15°C (intrinsic) Calibrated against Fluke-Hart Scientific 1502A (± 0.006-0.009°C)
	Volume Consumed, cu. ft. Pressure, “ W.C.	Fuel Inlet At Gas Valve Manifold	Diaphragm Gas Meter	American Meter AC-250 with IMAC 400-1000 pulser	2,000 pulses/cu. ft.
			Gauge Pressure Transmitter	Rosemount 3051C	± 0.065% of span (0-10”)
	Fuel Speciation & HHV	Batch sample onsite	Gas chromatograph	Agilent 3000	± 0.2%

	Temperature, °F	Fuel Inlet	Ultra Precise RTD – 1/4" dia	Rosemount 68 Series	± 0.15°C (intrinsic) Calibrated against Fluke-Hart Scientific 1502A (± 0.006-0.009°C)
Electricity	Electrical Energy Consumed	Total Power Consumption	Watt Transducer	Scientific Columbus XLGW10E1-A1 or Yokogawa 2489	± 0.1% of reading (500W = 1 mA) ± 0.2% of reading
	Line Voltage	115V Plug	Voltage transducer	Scientific Columbus VT110A2	± 0.15% of reading (150V = 1 mA); regulated with Powerstat variable auto-transformer
Flue Gases	Temperature, °F	Flue Outlet	Thermocouple	Omega, K-Type	± 1.8°F
	CO, CO2, O2, NO, NO_2		Portable flue gas analyzer	Land Instruments LANCOM III	CO2: ±0.5%, O2: ±1.0%, ±2.0% others
Data Acquisition Hardware/Software			Compact FieldPoint™ hardware and LabVIEW Software™	National Instruments	n/a

Appendix H: Laboratory Tests Non-DOE Draw Patterns

All patterns are derived from field-sampled daily hot water draws, averaged over a week and reduced to 10 minute bins [**Error! Reference source not found.**].

Storage Water Heater Testing:

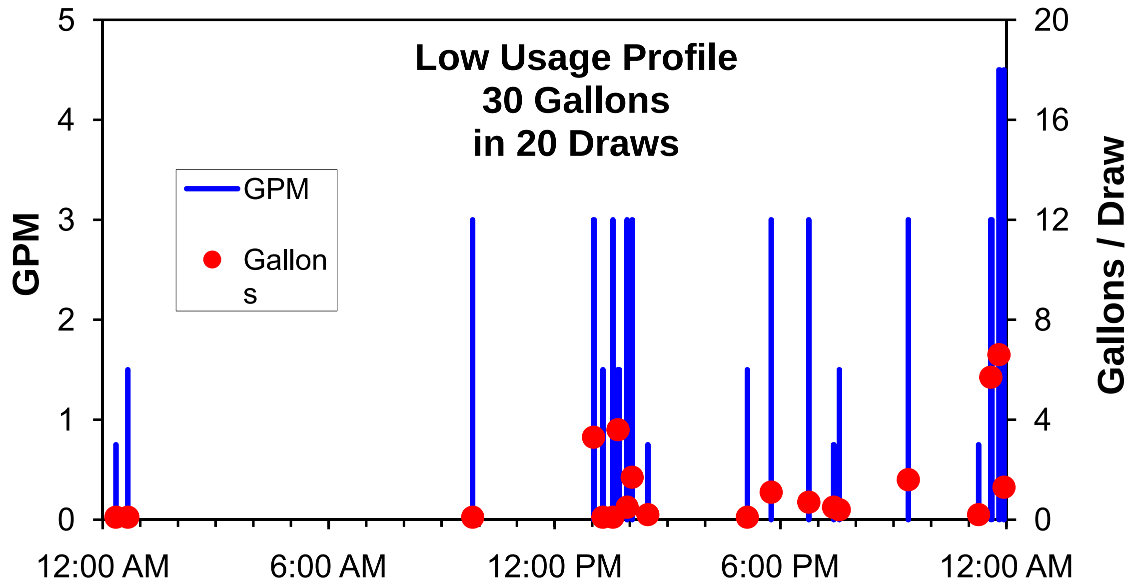


Figure 12: Low Use SWH Pattern

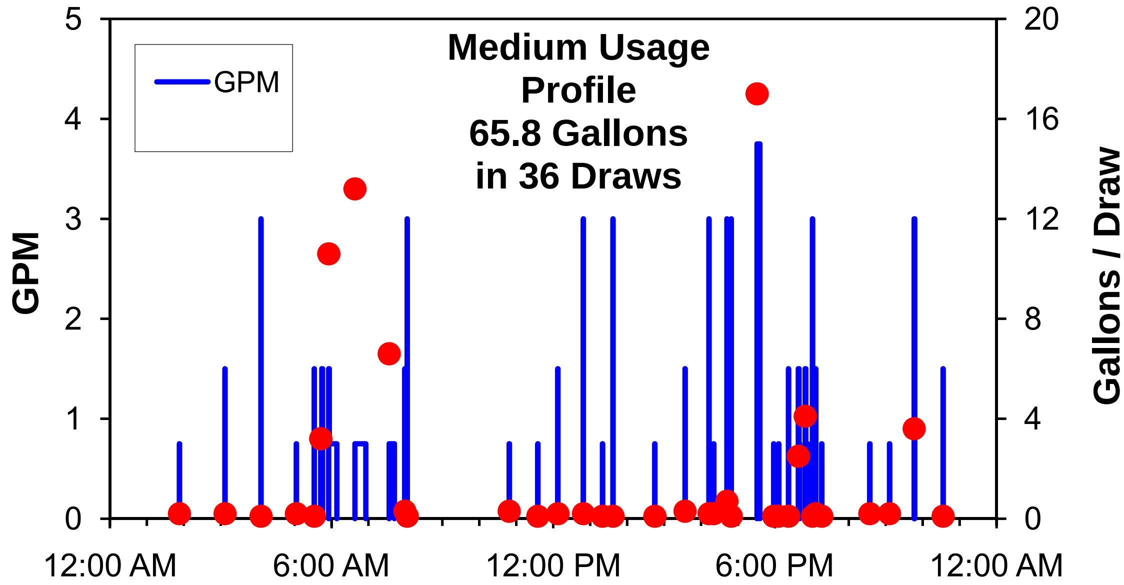


Figure 13: Mid Use SWH Pattern

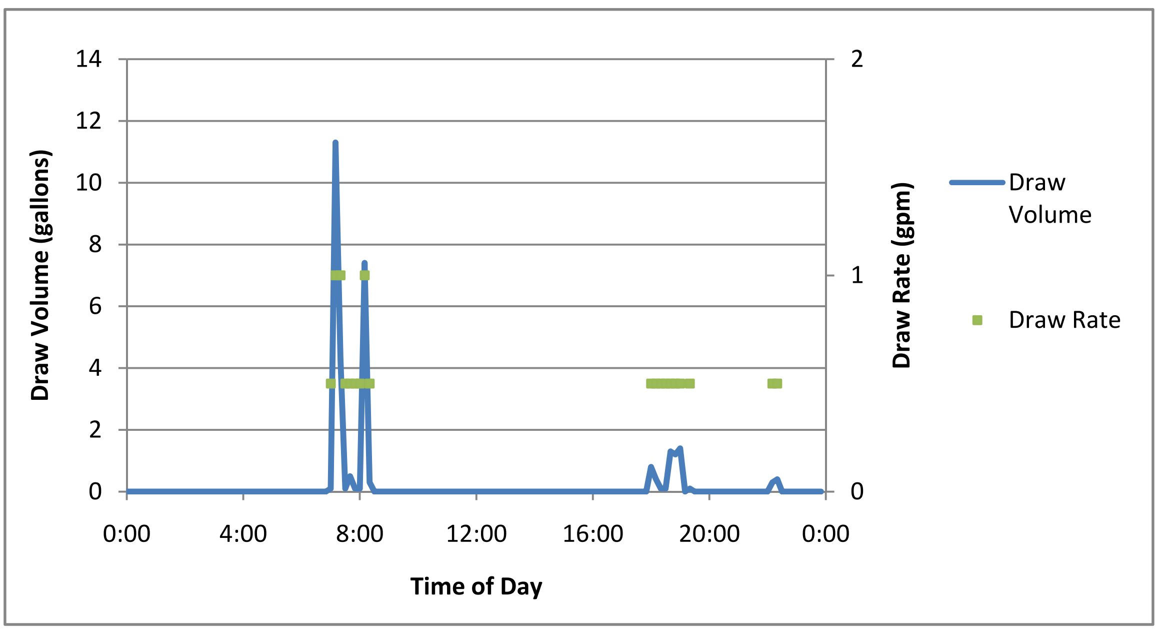


Figure 14: Low Use TWH Pattern

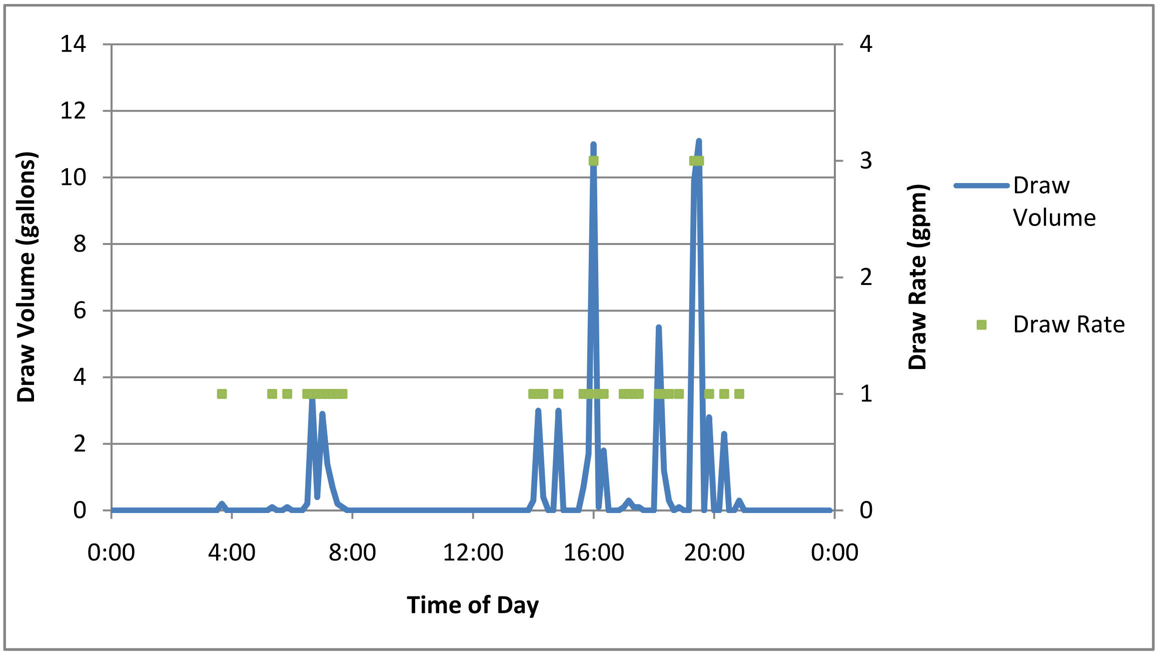


Figure 15: Mid Use TWH Pattern

Appendix I: Storage Water Heater Laboratory Tests Full Tabular and Graphical Datasets

Figure 16: SWH Test Stand at PG&E Applied Technology Services

Figure 17: Gas-fired Hybrid with Highlighted Components

Table 22: DOE Standard EF Test Results for Storage Water Heaters

	15 year old water heater	0.62 EF Atmos	0.67 EF Atmos/ Vent Damper	0.67 EF Power Vent	0.67 EF Direct Vent	0.70 EF Atmos/Fan Boost	Hybrid	Condensing Storage
$T_{Ambient}$ (F)	70.4	68.5	70.4	70.4	70.4	68.5	68.5	68.5
Gallons	64.4	64.3	64.4	64.4	64.3	64.4	64.4	64.4
Avg GPM	3.02	3.03	3.02	3.01	3.02	3.03	3.03	3.03
Avg T_{In} (F)	57.9	59.8	59.0	58.8	58.5	60.8	60.6	59.1
Avg T_{Tank} (F)	133.2	132.5	130.9	130.3	132.8	130.2	130.4	129.7
Avg T_{Out} (F)	139.3	135.1	140.4	132.3	139.7	130.6	130.8	134.8
HW Out (Btu)	42,706	39,839	42,741	38,645	42,706	36,989	37,150	39,846
HW Out (DOE)	42,960	42,888	42,985	38,877	42,896	39,789	40,121	43,114
ΔQ_{stored}	-2,549	-474	-937	-1259	-1,652	-3,096	-574	-204
HW Out + ΔQ_{stored}	40,158	39,364	41,803	37,386	41,054	33,893	36,576	39,642
Reheat Events	6	6	7	7	7	7	9	7
Avg BFR (Btu/hr)	34,066	36,235	34,312	38,408	42,596	33,209	69,440	67,202
Gas (SCF)	66.45	64.02	61.14	56.26	61.85	50.38	51.75	51.64
Gas (Therms)	0.678	0.654	0.624	0.574	0.631	0.515	0.529	0.528
Electricity (Wh)	0	0	148.4	291.8	233.3	212.4	376.4	127.2
Energy In (Btu)	67,826	65,409	62,906	58,419	63,924	52,198	54,162	53,197
η recovery	78.7%	74.7%	74.8%	74.7%	74.8%	75.8%	76.1%	83.9%
EF (Simple)	0.592	0.602	0.665	0.640	0.642	0.649	0.675	0.745
EF (ASHRAE)	0.590	0.606	0.659	0.643	0.639	0.664	0.684	0.747
EF (DOE)	0.586	0.602	0.657	0.639	0.636	0.659	0.676	0.743
E_{annual} (Therms)	253	247	226	232	234	225	220	200
Avg Power On (W)	0	0	8.4	180.3	144.9	26.1	227.5	134.1
Avg Power Off (W)	0	0	5.9	0.8	0.6	7.6	7.9	0.7
Standby BFR (Btu/hr)	458	488	0	0	0	0	0	0

Table 23: GTI Mid-Draw Profile Results for Storage Water Heaters

	15 year old" water heater	0.62 EF Atmos	0.67 EF Atmos/ Vent Damper	0.67 EF Power Vent	0.67 EF Direct Vent	0.70 EF Atmos/Fan Boost	Hybrid	Condensing Storage
$T_{Ambient}$ (F)	70.4	67.9	69.0	69.0	70.4	68.2	68.2	67.9
Gallons	66.0	66.2	66.1	66.0	66.0	66.2	66.1	66.2
Draw Events	33	33	33	33	33	33	33	33
Avg GPM	1.39	1.47	1.41	1.41	1.41	1.46	1.46	1.47
Avg T_{In} (F)	59.4	58.7	59.3	59.4	59.9	58.2	57.8	57.8
Avg T_{Tank} (F)	132.1	132.0	135.4	133.5	133.4	136.3	130.8	127.2
Avg T_{Out} (F)	136.9	134.9	146.4	137.0	138.0	137.6	131.2	132.5
HW Out (Btu)	41,980	41,433	47,210	42,113	42,347	43,202	39,910	40,623
ΔQ_{stored}	44	556	-708	-830	-74	62	65	633
HW Out + ΔQ_{stored}	42,024	41,990	46,502	41,284	42,273	43,265	39,975	41,256
Reheat Events	6	7	12	8	8	12	17	6
Avg BFR (Btu/hr)	34,637	36,419	34,425	38,214	42,517	32,994	57.080	69,325
Nat. Gas (SCF)	68.37	68.16	68.58	62.56	64.14	63.51	55.95	55.05
Nat. Gas (Therms)	0.698	0.696	0.699	0.637	0.655	0.650	0.573	0.562
Electricity (Wh)	0	0	145.5	326.9	245.3	219.0	422.7	133.7
Energy Input (Btu)	69,778	69,597	70,365	64,859	66,302	65,759	58,722	56,670
EF (Simple)	0.602	0.603	0.661	0.637	0.638	0.658	0.679	0.728
Avg Power On (W)	0	0	8.3	178.7	146.8	25.8	210.7	134.1
Avg Power Off (W)	0	0	5.8	0.8	0.7	7.6	7.9	0.7
Standby BFR (Btu/hr)	460	432	0	0	0	0	0	0

Table 24: GTI Low Draw Profile Results for Storage Water Heaters

	15 year old" water heater	0.62 EF Atmos	0.67 EF Atmos/ Vent Damper	0.67 EF Power Vent	0.67 EF Direct Vent	0.70 EF Atmos/Fan Boost	Hybrid	Condensing Storage
$T_{Ambient}$ (F)	69.3	68.6	68.2	69.0	69.8	67.2	68.4	68.6
Gallons	30.6	30.4	30.4	30.3	31.1	30.4	30.4	30.4
Draw Events	18	18	18	17	19	18	18	18
Avg GPM	0.90	0.83	0.79	0.88	0.97	0.84	0.82	0.83
Avg T_{In} (F)	59.9	60.1	60.3	60.5	61.0	58.0	57.3	58.1
Avg T_{Tank} (F)	131.6	132.7	140.2	132.6	133.1	135.8	130.1	129.9
Avg T_{Out} (F)	129.1	130.7	140.1	131.5	135.6	134.2	131.1	129.6
HW Out (Btu)	17,452	17,676	19,943	17,729	19,072	19,060	18,360	17,907
ΔQ_{stored}	74	999	2106	434	47	361	221	-436
HW Out + ΔQ_{stored}	17,525	18,675	22,048	18,163	19,120	19,421	18,581	17,470
Reheat Events	3	3	4	4	5	6	8	3
Avg BFR (Btu/hr)	35,025	36,361	34,991	38,533	42,567	33,655	48,961	69,342
Nat. Gas (SCF)	39.02	37.52	37.37	33.03	34.94	34.26	31.09	27.27
Nat. Gas (Therms)	0.399	0.385	0.384	0.338	0.357	0.352	0.319	0.280
Electricity (Wh)	0	0	144.0	179.8	141.2	203.8	336.8	74.8
Energy Input (Btu)	39,912	38,541	38,879	34,433	35,239	35,884	33,080	28,268
EF (Simple)	0.439	0.484	0.567	0.528	0.529	0.541	0.562	0.618
Avg Power On (W)	0	0	8.4	177.5	144.1	25.8	201.3	133.0
Avg Power Off (W)	0	0	5.9	0.8	0.7	7.7	7.9	0.7
Standby BFR (Btu/hr)	428	456	0	0	0	0	0	0

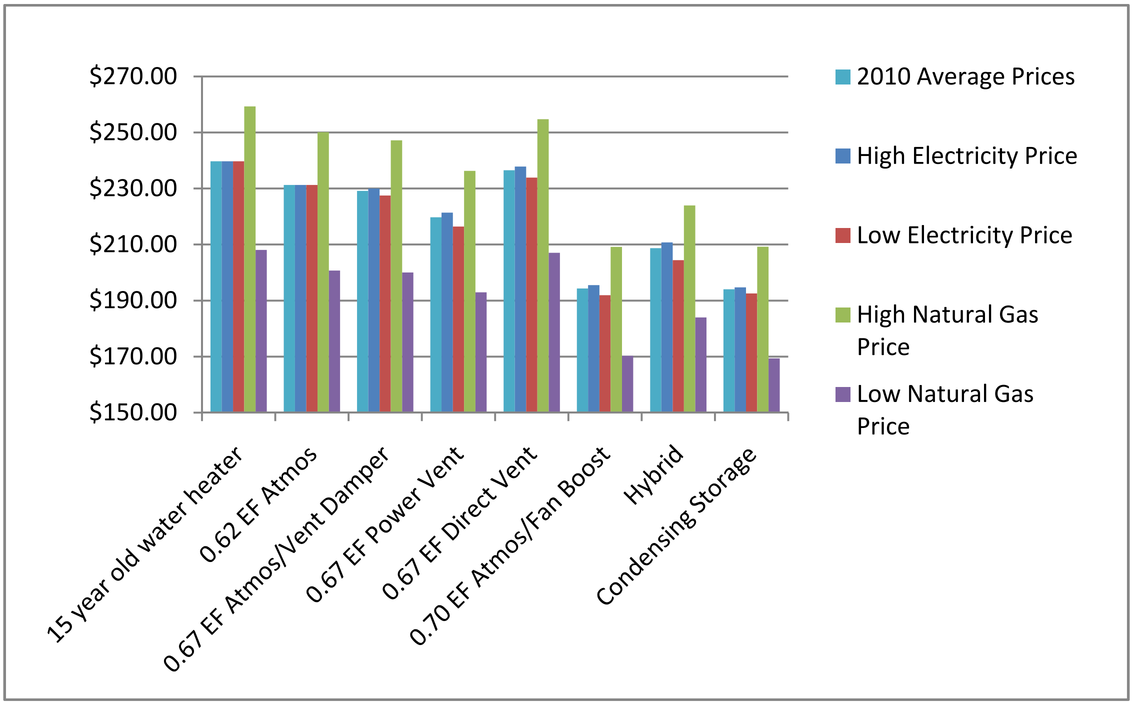


Figure 18: DOE Standard EF Energy Sensitivity Analysis

Table 25: DOE Standard EF Test Energy Price Sensitivity Analysis – Annual Energy Cost

	15 year old water heater	**0.62 EF Atmos**	**0.67 EF Atmos/Vent Damper**	**0.67 EF Power Vent**	**0.67 EF Direct Vent**	**0.70 EF Atmos/ Fan Boost**	**Hybrid**	**Conde-nsing Storage**
2010 Average Prices	$239.74	$231.25	$229.17	$219.74	$236.53	$194.31	$208.69	$194.01
High Electricity Price	$239.74	$231.25	$230.00	$221.37	$237.83	$195.50	$210.79	$194.72
Low Electricity Price	$239.74	$231.25	$227.49	$216.43	$233.88	$191.90	$204.42	$192.57
High Natural Gas	$259.31	$250.13	$247.19	$236.31	$254.75	$209.18	$223.96	$209.25
Low Natural Gas	$208.08	$200.71	$200.04	$192.94	$207.07	$170.26	$183.99	$169.36

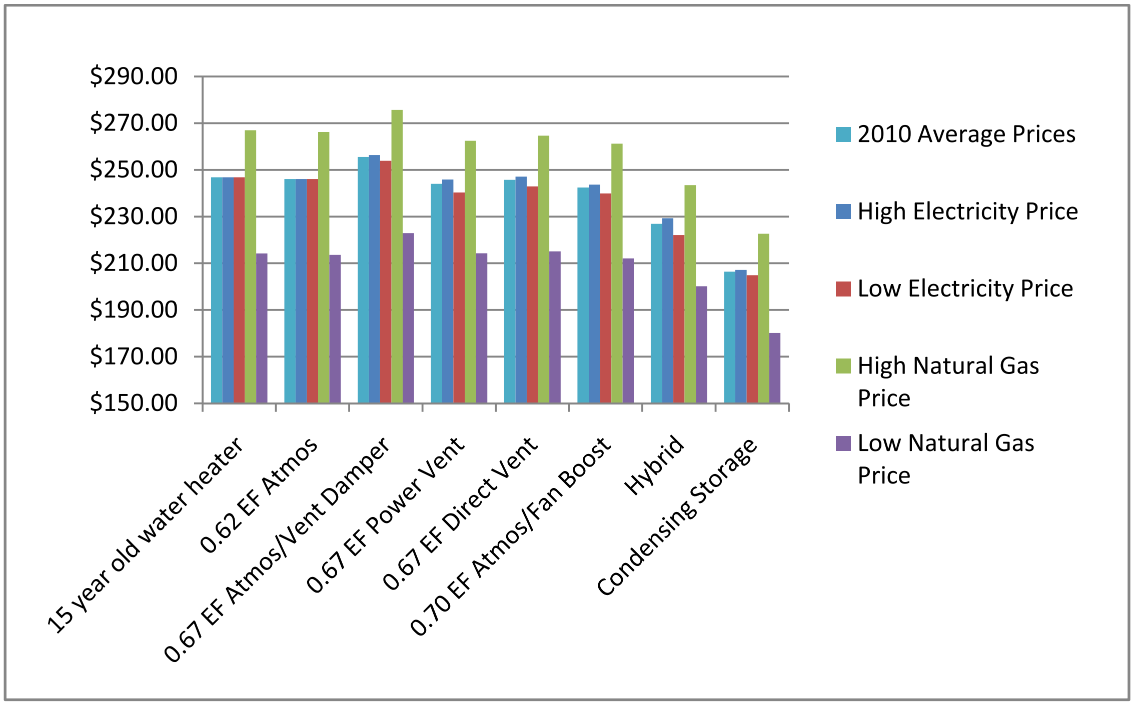


Figure 19: GTI Mid-Draw Profile Energy Price Sensitivity Analysis – Annual Energy Cost

Table 26: GTI Mid-Draw Profile Energy Price Sensitivity Analysis – Annual Energy Cost

	15 year old water heater	0.62 EF Atmos	0.67 EF Atmos/Vent Damper	0.67 EF Power Vent	0.67 EF Direct Vent	0.70 EF Atmos/ Fan Boost	Hybrid	Conde-nsing Storage
2010 Average Prices	$246.81	$246.10	$255.53	$244.03	$245.71	$242.43	$226.91	$206.41
High Electricity Price	$246.81	$246.10	$256.34	$245.86	$247.08	$243.65	$229.27	$207.15
Low Electricity Price	$246.81	$246.10	$253.87	$240.32	$242.92	$239.94	$222.11	$204.89
High Natural Gas Price	$266.96	$266.20	$275.71	$262.42	$264.62	$261.19	$243.45	$222.63
Low Natural Gas Price	$214.22	$213.60	$222.89	$214.29	$215.12	$212.07	$200.15	$180.16

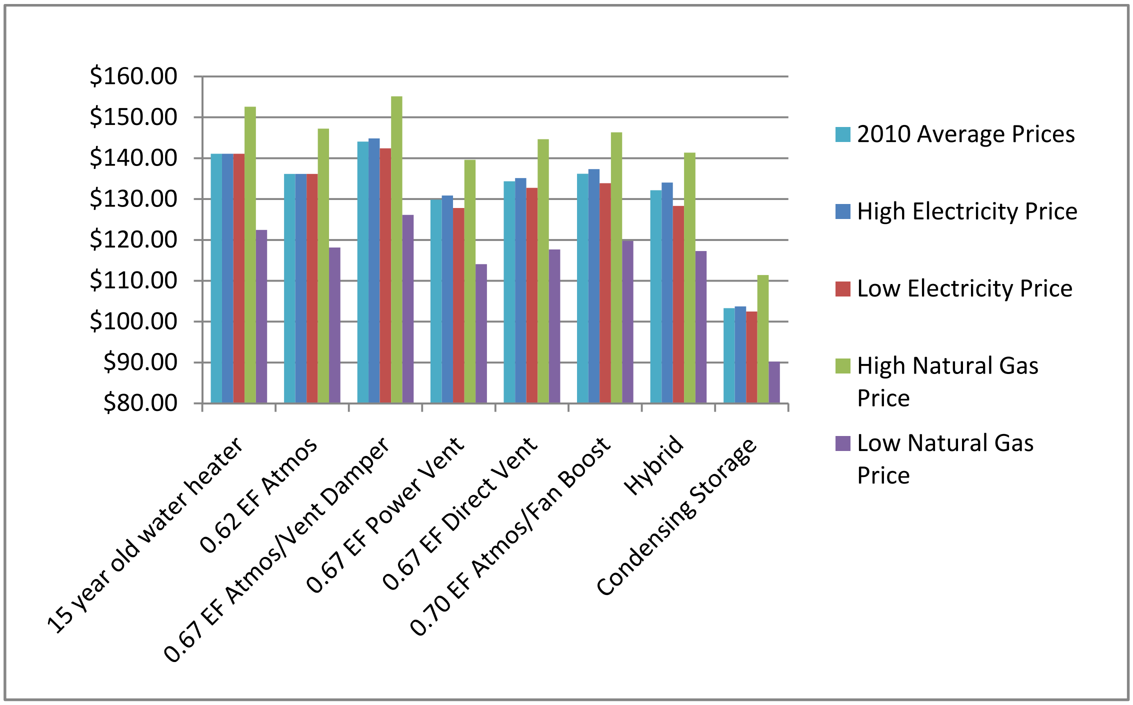
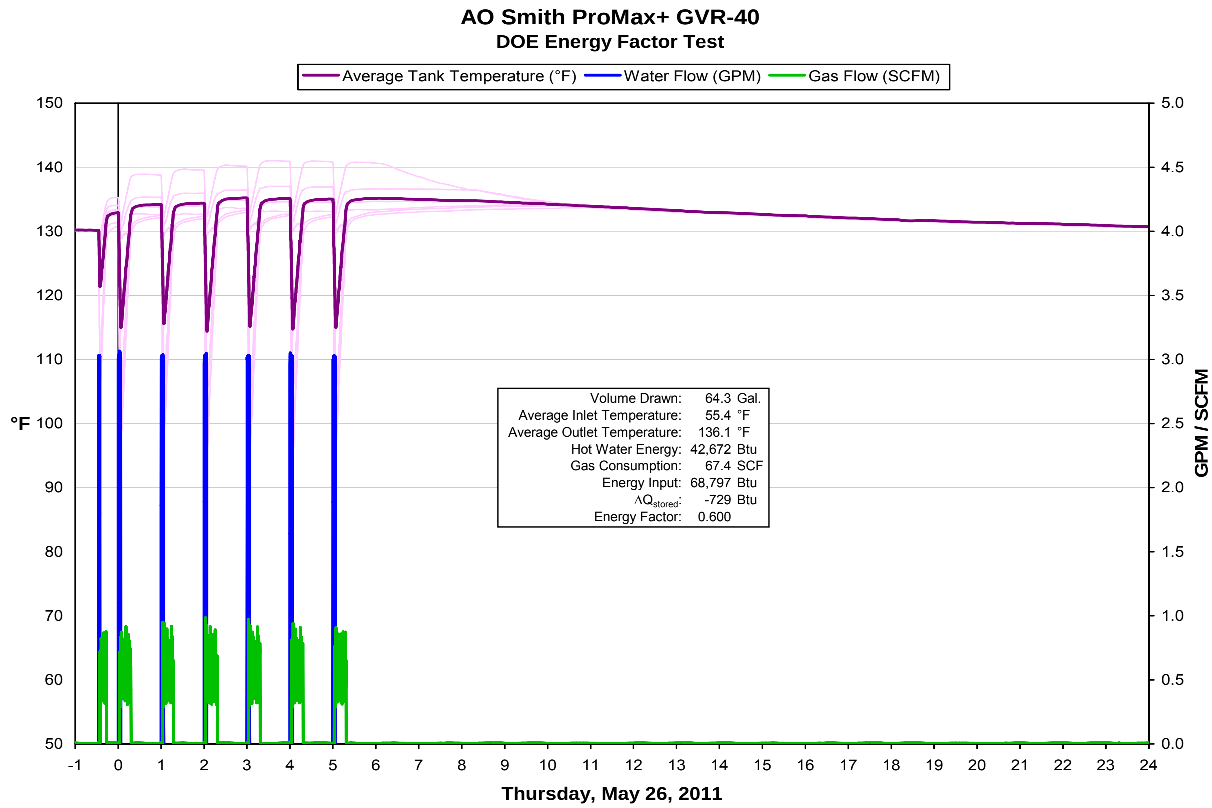


Figure 20: GTI Low-Draw Profile Energy Price Sensitivity Analysis – Annual Energy Cost

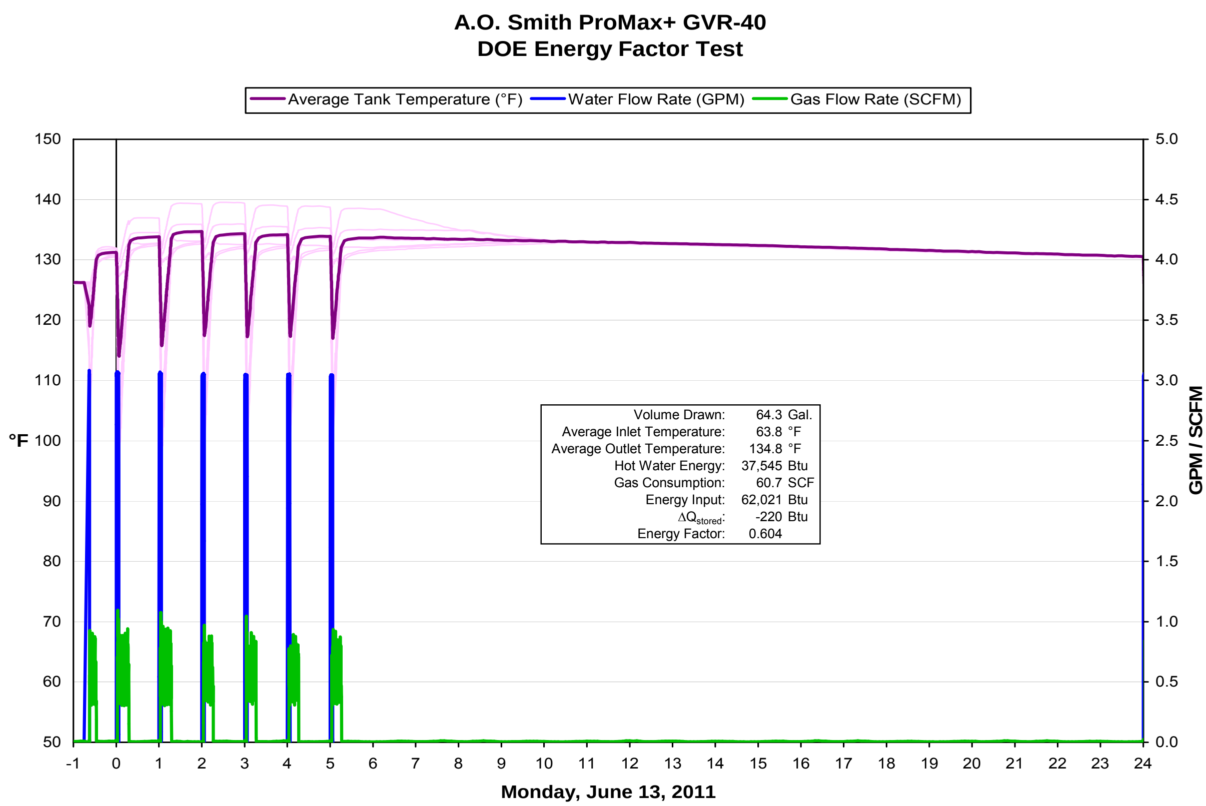
Table 27: GTI Low-Draw Energy Price Sensitivity Analysis – Annual Energy Cost

	15 year old water heater	0.62 EF Atmos	0.67 EF Atmos/Vent Damper	0.67 EF Power Vent	0.67 EF Direct Vent	0.70 EF Atmos/ Fan Boost	Hybrid	Conde-nsing Storage
2010 Average Prices	$141.08	$136.13	$144.06	$129.85	$134.35	$136.18	$132.16	$103.31
High Electricity Price	$141.08	$136.13	$144.86	$130.86	$135.14	$137.32	$134.04	$103.72
Low Electricity Price	$141.08	$136.13	$142.42	$127.81	$132.75	$133.87	$128.34	$102.46
High Natural Gas Price	$152.60	$147.25	$155.15	$139.61	$144.66	$146.34	$141.37	$111.39
Low Natural Gas Price	$122.45	$118.16	$126.13	$114.07	$117.68	$119.74	$117.26	$90.23

The following graphics were generated by PG&E during in the reporting of their results, presented in the order of equipment tested as shown in **Error! Reference source not found.**.

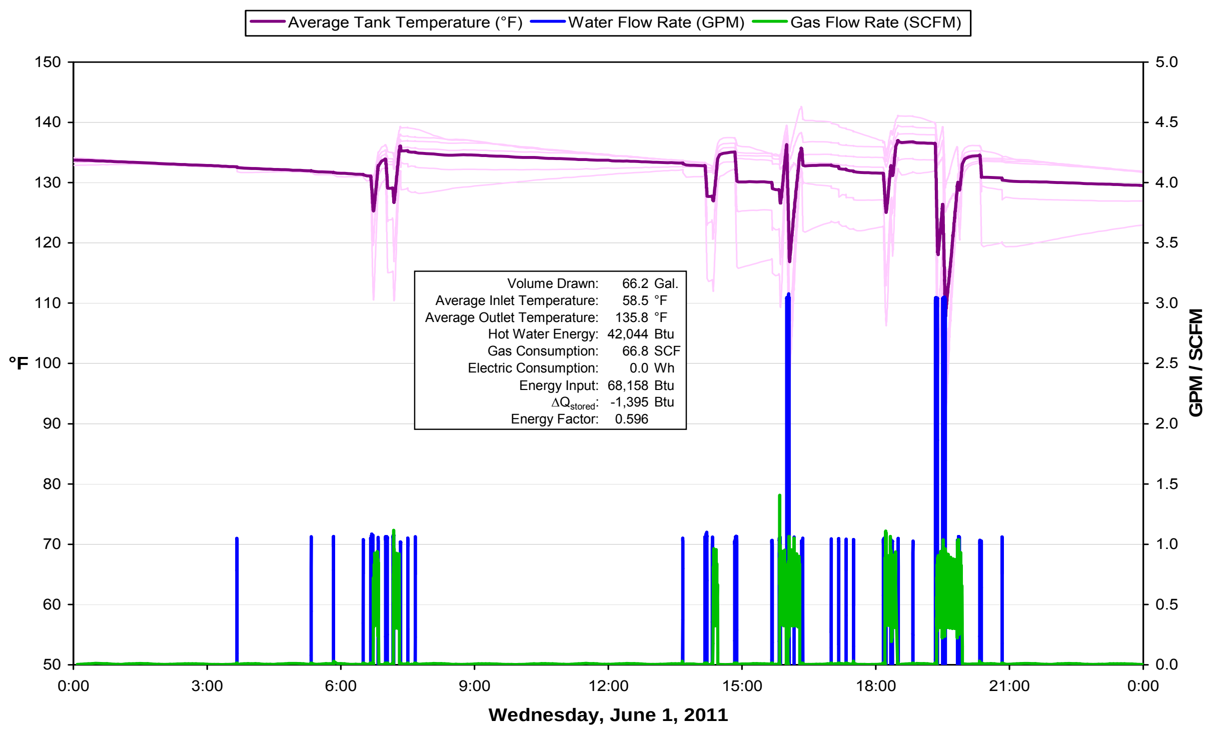


AO Smith ProMax+ GVR-40
DOE Energy Factor Test
Average Tank Temperature (°F)
Water Flow (GPM)
Gas Flow (SCFM)
°F
GPM / SCFM
Thursday, May 26, 2011
Volume Drawn: 64.3 Gal.
Average Inlet Temperature: 55.4 °F
Average Outlet Temperature: 136.1 °F
Hot Water Energy: 42,672 Btu
Gas Consumption: 67.4 SCF
Energy Input: 68,797 Btu
ΔQstored: -729 Btu
Energy Factor: 0.600

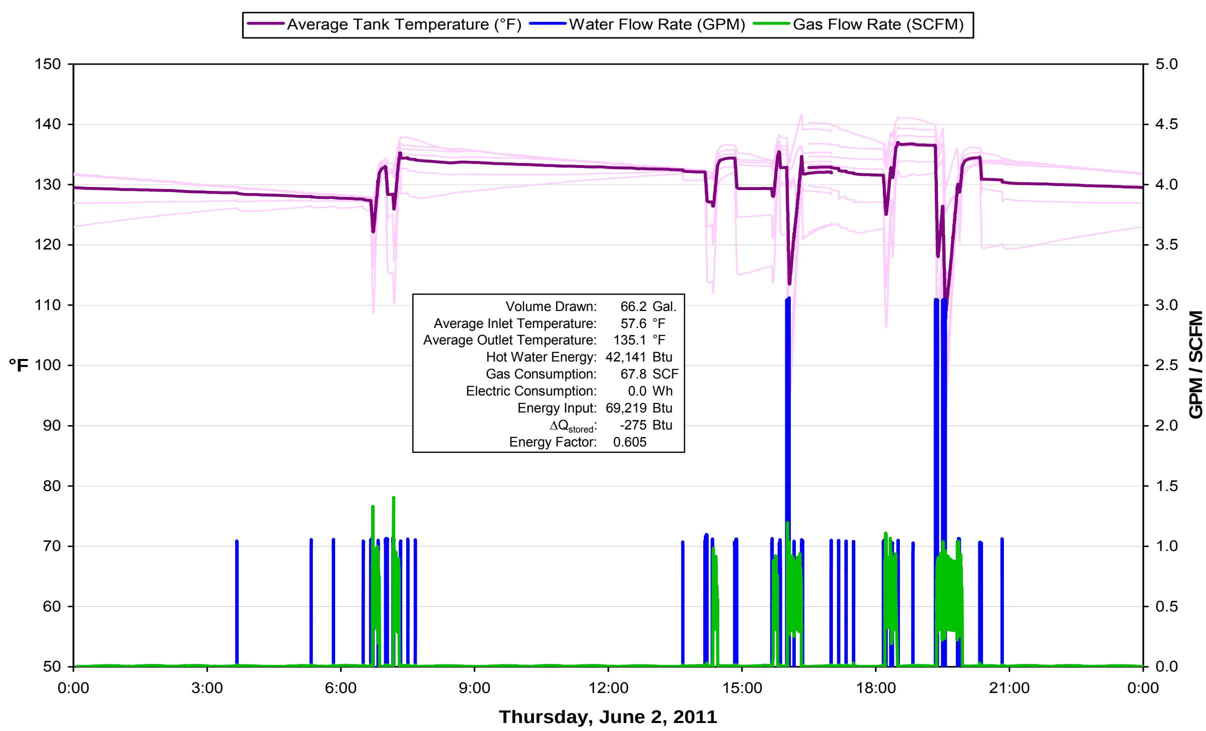


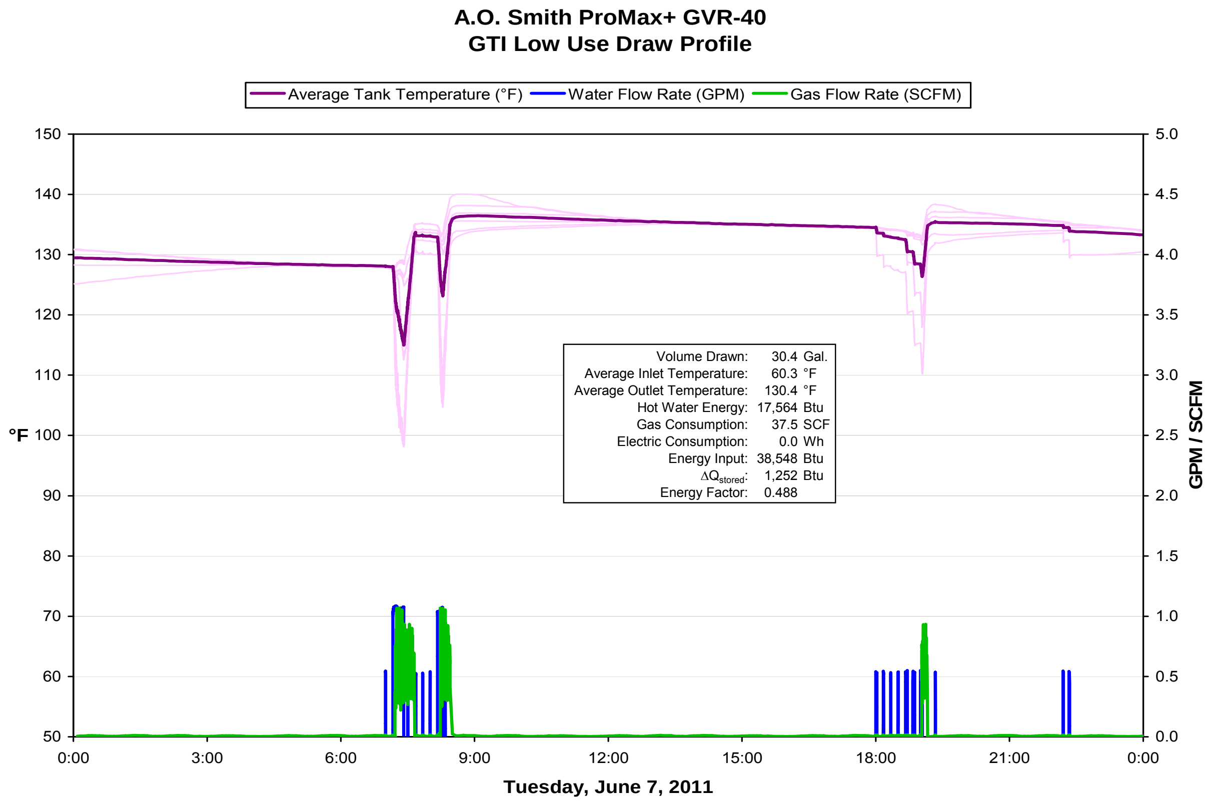
A.O. Smith ProMax+ GVR-40
DOE Energy Factor Test
Average Tank Temperature (°F)
Water Flow Rate (GPM)
Gas Flow Rate (SCFM)
°F
GPM / SCFM
Monday, June 13, 2011
Volume Drawn: 64.3 Gal.
Average Inlet Temperature: 63.8 °F
Average Outlet Temperature: 134.8 °F
Hot Water Energy: 37,545 Btu
Gas Consumption: 60.7 SCF
Energy Input: 62,021 Btu
ΔQstored: -220 Btu
Energy Factor: 0.604

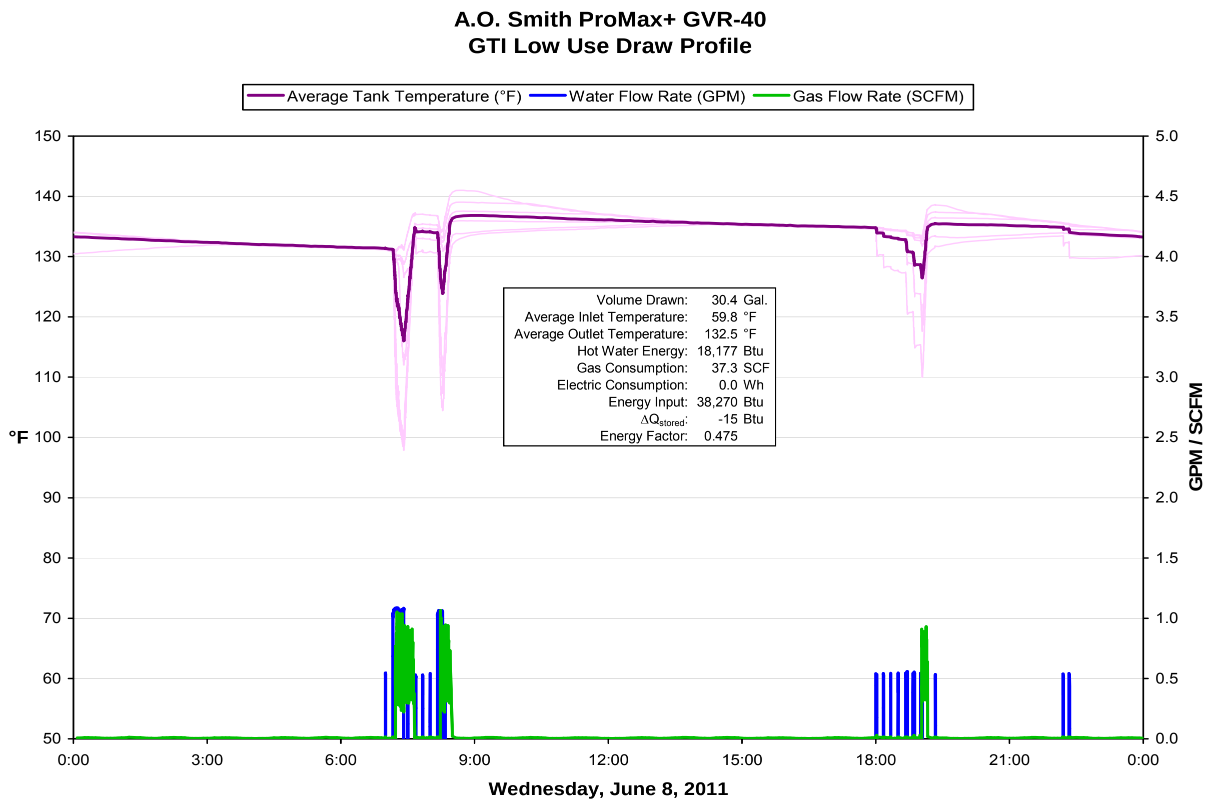
A.O. Smith ProMax+ GVR-40
GTI Medium Use Draw Profile

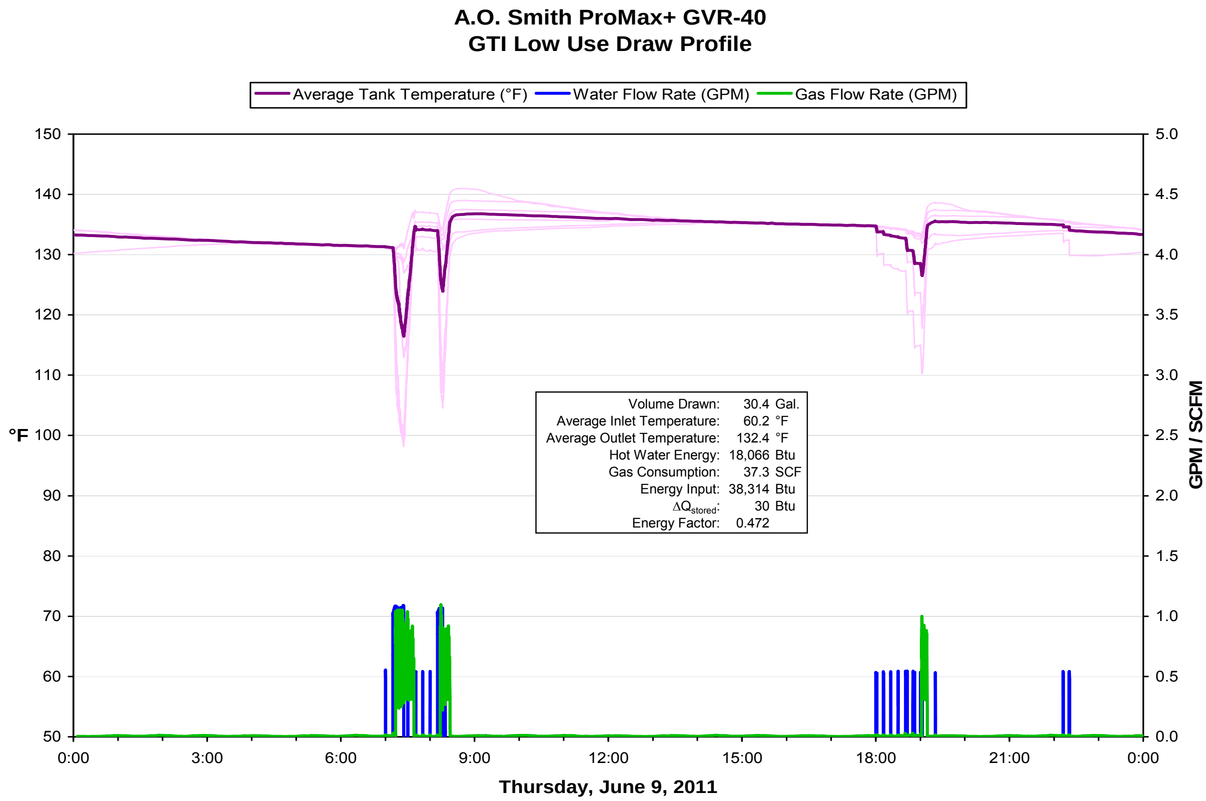


A.O. Smith ProMax+ GVR-40
GTI Medium Use Draw Profile

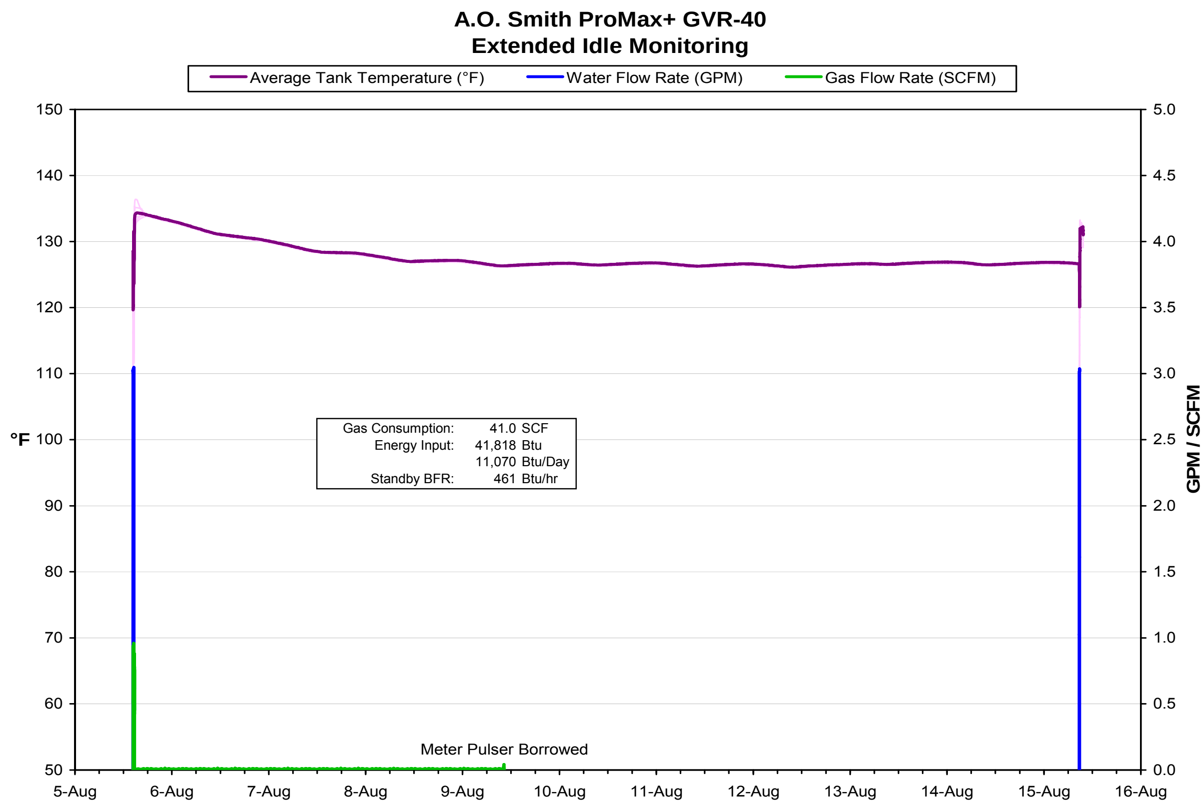



A.O. Smith ProMax+ GVR-40
GTI Low Use Draw Profile
Average Tank Temperature (°F)
Water Flow Rate (GPM)
Gas Flow Rate (SCFM)
Volume Drawn: 30.4 Gal.
Average Inlet Temperature: 60.3 °F
Average Outlet Temperature: 130.4 °F
Hot Water Energy: 17,564 Btu
Gas Consumption: 37.5 SCF
Electric Consumption: 0.0 Wh
Energy Input: 38,548 Btu
ΔQstored: 1,252 Btu
Energy Factor: 0.488
°F
GPM / SCFM
Tuesday, June 7, 2011

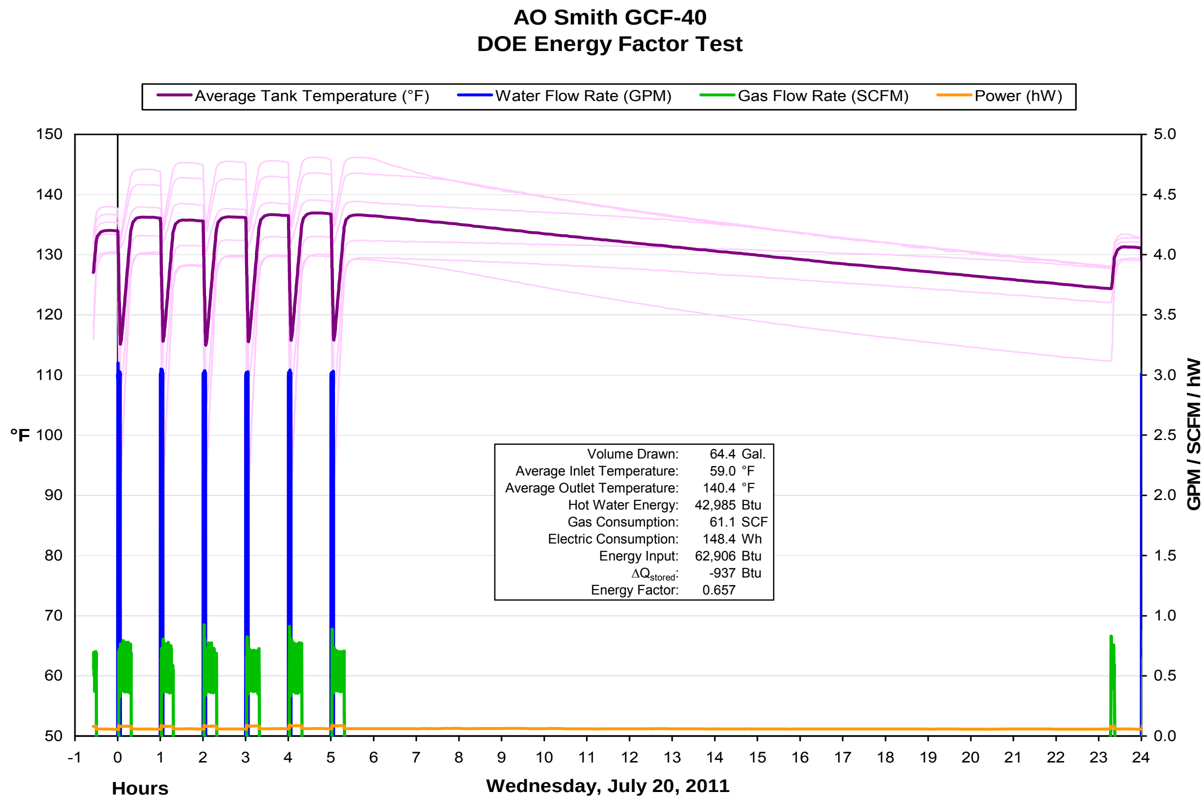

A.O. Smith ProMax+ GVR-40
GTI Low Use Draw Profile
Average Tank Temperature (°F)
Water Flow Rate (GPM)
Gas Flow Rate (SCFM)
Volume Drawn: 30.4 Gal.
Average Inlet Temperature: 59.8 °F
Average Outlet Temperature: 132.5 °F
Hot Water Energy: 18,177 Btu
Gas Consumption: 37.3 SCF
Electric Consumption: 0.0 Wh
Energy Input: 38,270 Btu
ΔQstored: -15 Btu
Energy Factor: 0.475
°F
GPM / SCFM
Wednesday, June 8, 2011

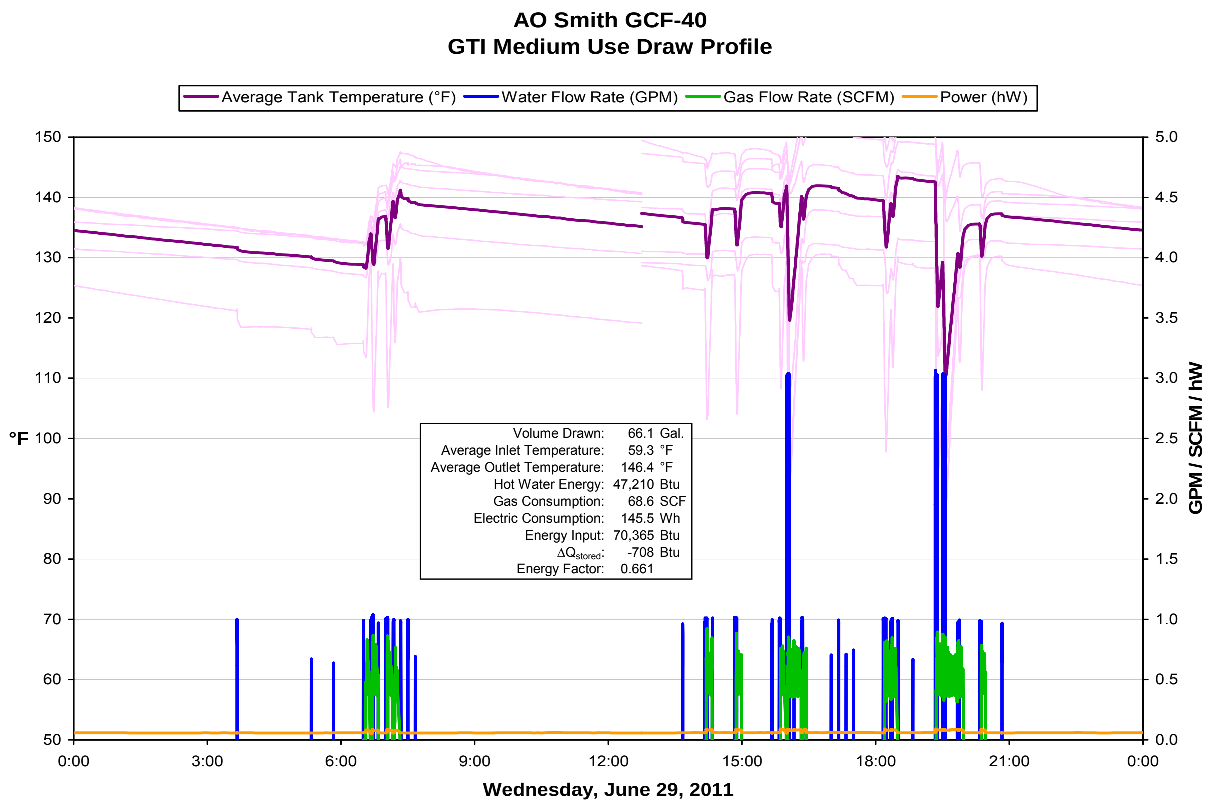


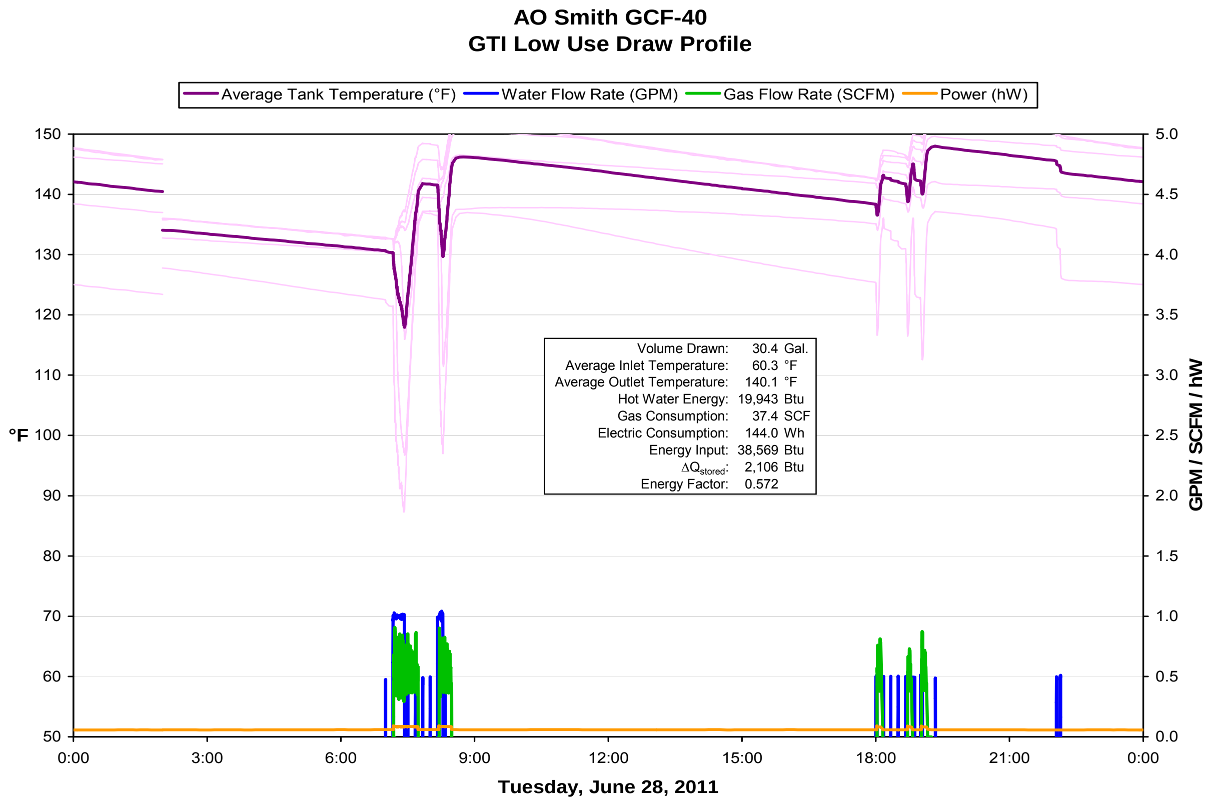
A.O. Smith ProMax+ GVR-40
GTI Low Use Draw Profile
Average Tank Temperature (°F)
Water Flow Rate (GPM)
Gas Flow Rate (GPM)
°F
GPM / SCFM
Volume Drawn: 30.4 Gal.
Average Inlet Temperature: 60.2 °F
Average Outlet Temperature: 132.4 °F
Hot Water Energy: 18,066 Btu
Gas Consumption: 37.3 SCF
Energy Input: 38,314 Btu
ΔQstored: 30 Btu
Energy Factor: 0.472
Thursday, June 9, 2011

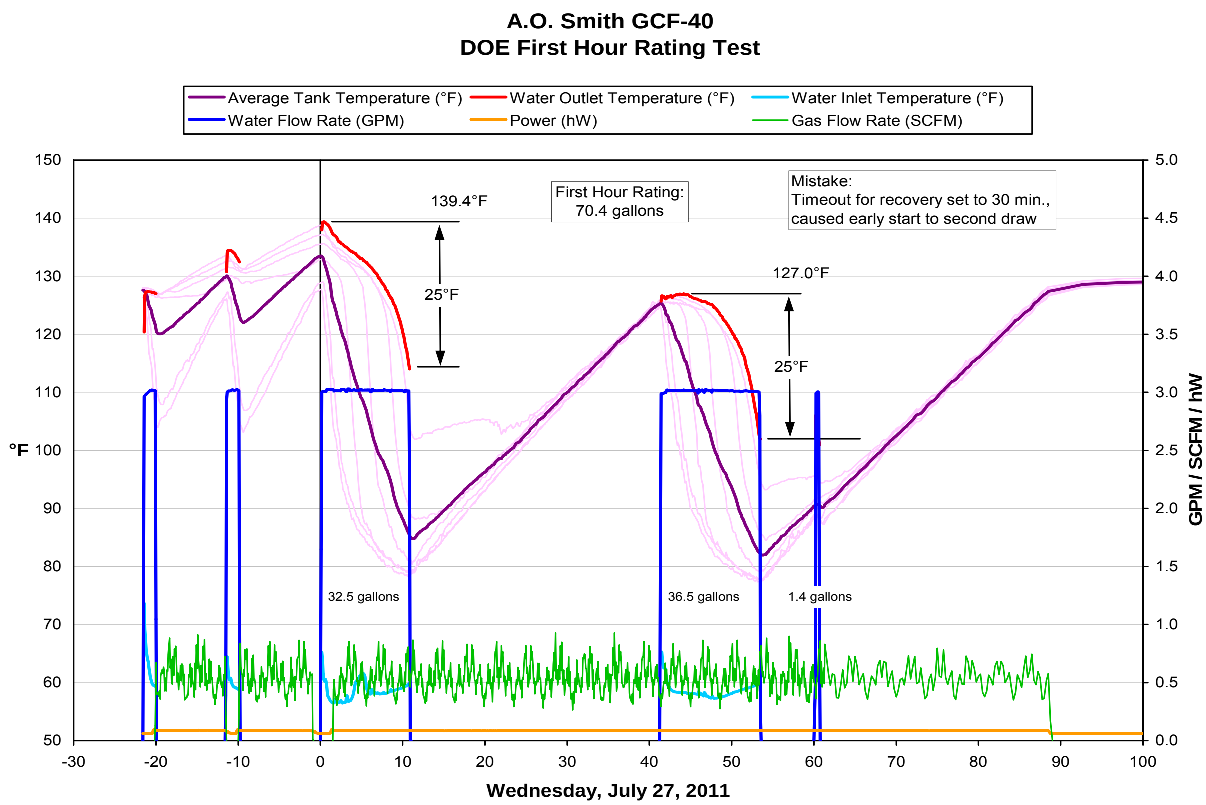


A.O. Smith ProMax+ GVR-40
Extended Idle Monitoring
Average Tank Temperature (°F)
Water Flow Rate (GPM)
Gas Flow Rate (SCFM)
°F
GPM / SCFM
Gas Consumption: 41.0 SCF
Energy Input: 41,818 Btu
11,070 Btu/Day
Standby BFR: 461 Btu/hr
Meter Pulser Borrowed

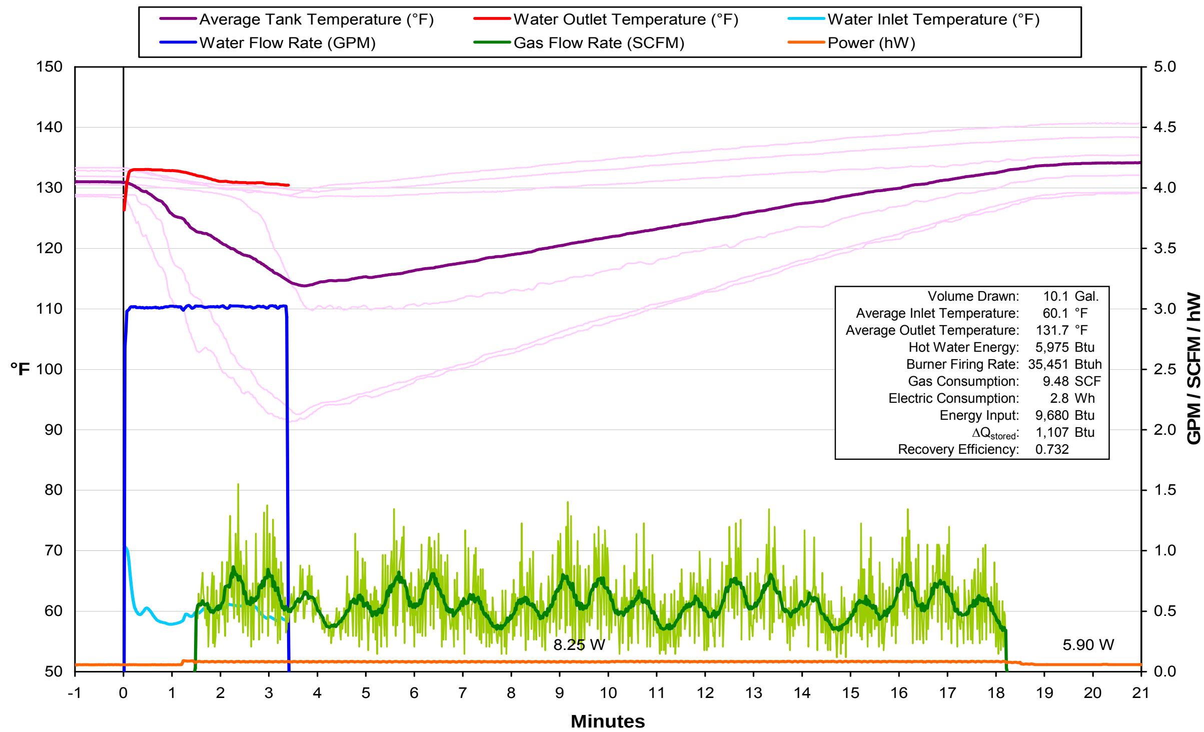

AO Smith GCF-40
DOE Energy Factor Test
Average Tank Temperature (°F)
Water Flow Rate (GPM)
Gas Flow Rate (SCFM)
Power (hW)
°F
GPM / SCFM / hW
Hours
Wednesday, July 20, 2011
Volume Drawn: 64.4 Gal.
Average Inlet Temperature: 59.0 °F
Average Outlet Temperature: 140.4 °F
Hot Water Energy: 42,985 Btu
Gas Consumption: 61.1 SCF
Electric Consumption: 148.4 Wh
Energy Input: 62,906 Btu
ΔQstored: -937 Btu
Energy Factor: 0.657


AO Smith GCF-40
GTI Medium Use Draw Profile
Average Tank Temperature (°F)
Water Flow Rate (GPM)
Gas Flow Rate (SCFM)
Power (hW)
°F
GPM / SCFM / hW
Wednesday, June 29, 2011
Volume Drawn: 66.1 Gal.
Average Inlet Temperature: 59.3 °F
Average Outlet Temperature: 146.4 °F
Hot Water Energy: 47,210 Btu
Gas Consumption: 68.6 SCF
Electric Consumption: 145.5 Wh
Energy Input: 70,365 Btu
ΔQstored: -708 Btu
Energy Factor: 0.661

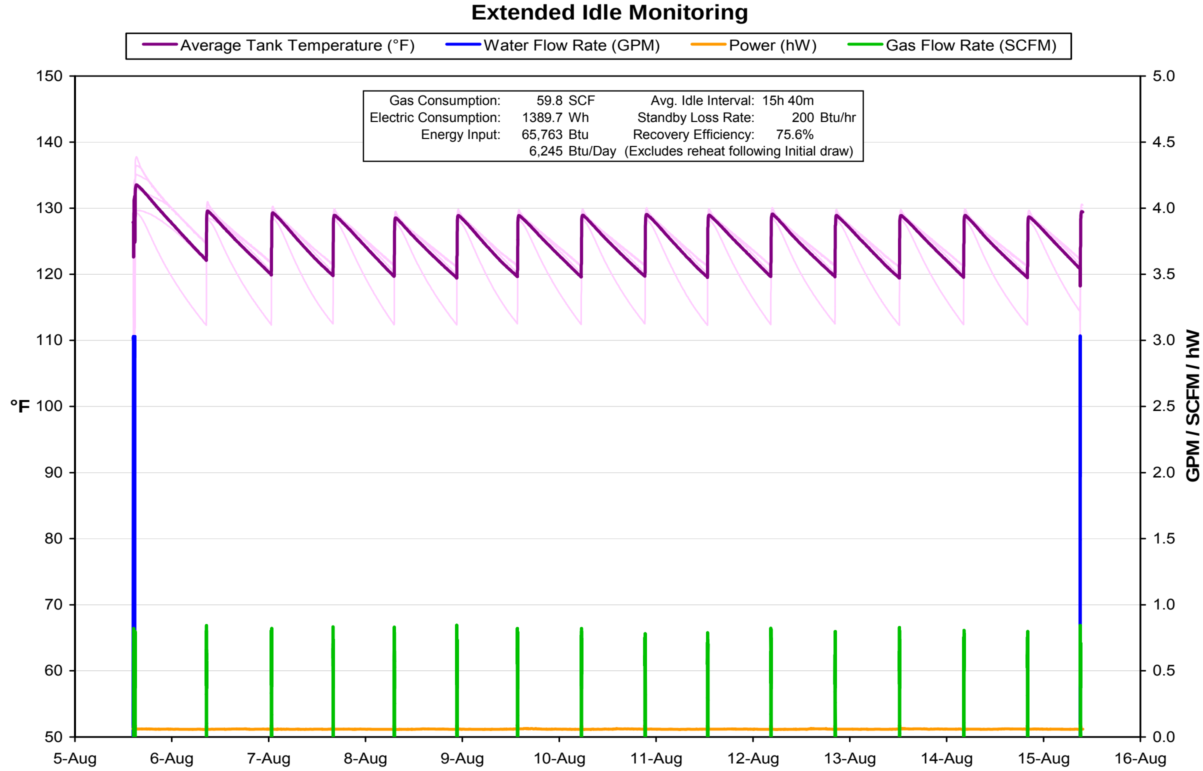

AO Smith GCF-40
GTI Low Use Draw Profile
Average Tank Temperature (°F)
Water Flow Rate (GPM)
Gas Flow Rate (SCFM)
Power (hW)
Volume Drawn: 30.4 Gal.
Average Inlet Temperature: 60.3 °F
Average Outlet Temperature: 140.1 °F
Hot Water Energy: 19,943 Btu
Gas Consumption: 37.4 SCF
Electric Consumption: 144.0 Wh
Energy Input: 38,569 Btu
ΔQ_{stored}: 2,106 Btu
Energy Factor: 0.572
°F
GPM / SCFM / hW
Tuesday, June 28, 2011


A.O. Smith GCF-40
DOE First Hour Rating Test
Average Tank Temperature (°F)
Water Outlet Temperature (°F)
Water Inlet Temperature (°F)
Water Flow Rate (GPM)
Power (hW)
Gas Flow Rate (SCFM)
First Hour Rating:
70.4 gallons
Mistake:
Timeout for recovery set to 30 min.,
caused early start to second draw
139.4°F
25°F
127.0°F
25°F
32.5 gallons
36.5 gallons
1.4 gallons
°F
GPM / SCFM / hW
Wednesday, July 27, 2011

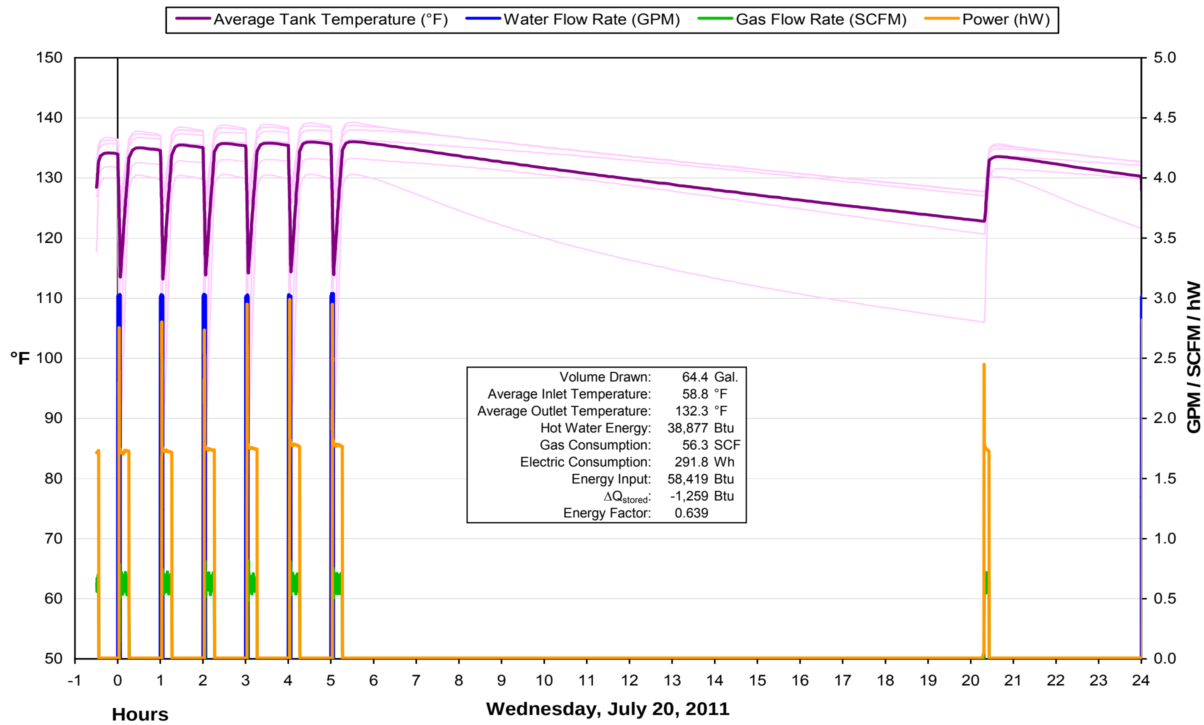
A.O. Smith GCF-40
Power Consumption Detail
(1 second scan rate)



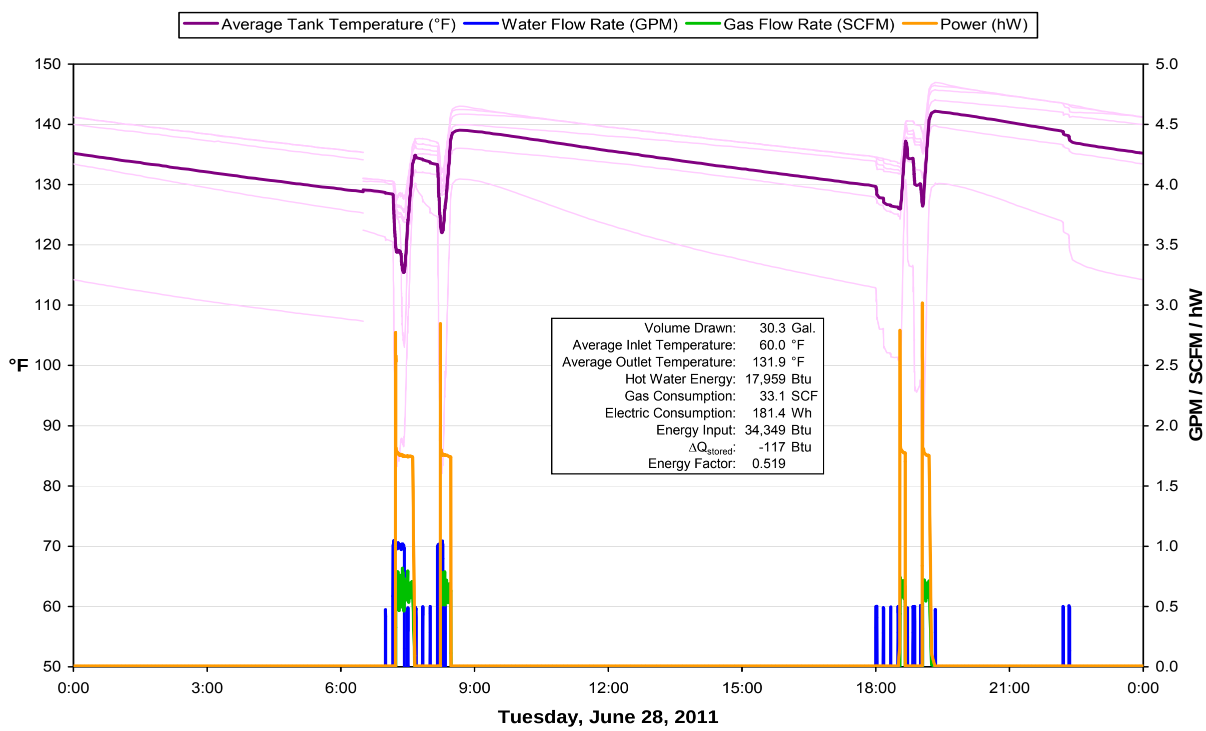
A.O. Smith GCF-40
Extended Idle Monitoring



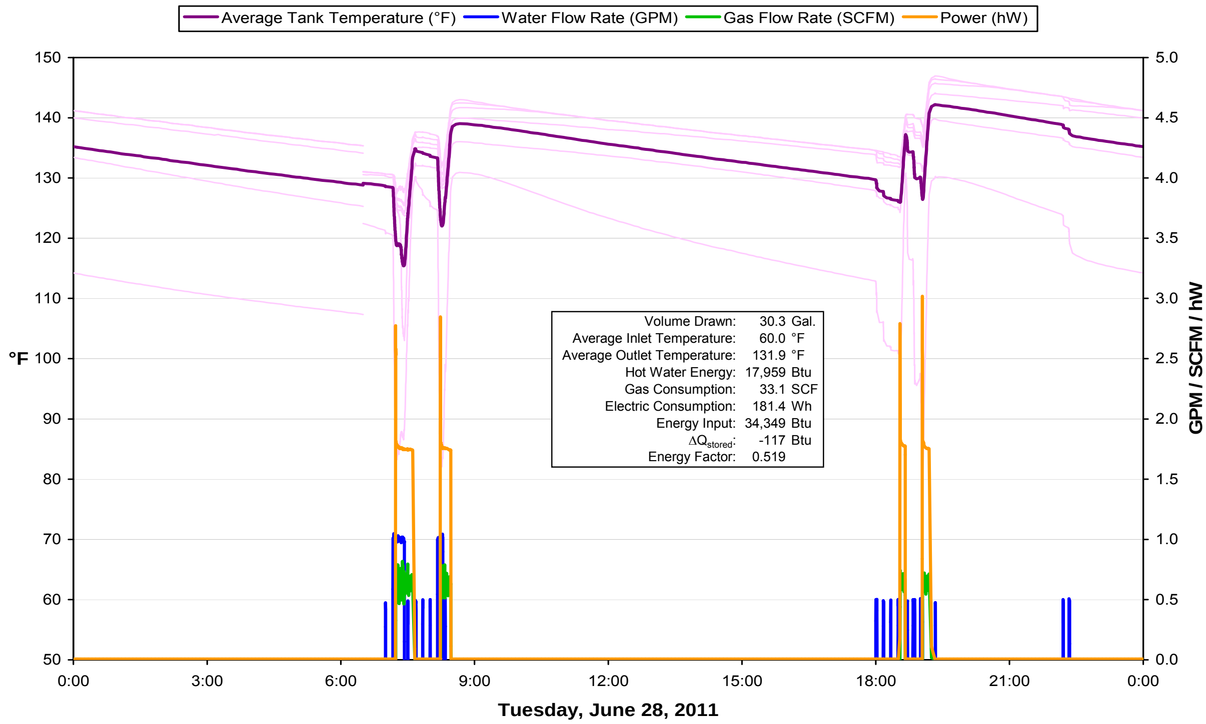
AO Smith GPVR-40
DOE Energy Factor Test



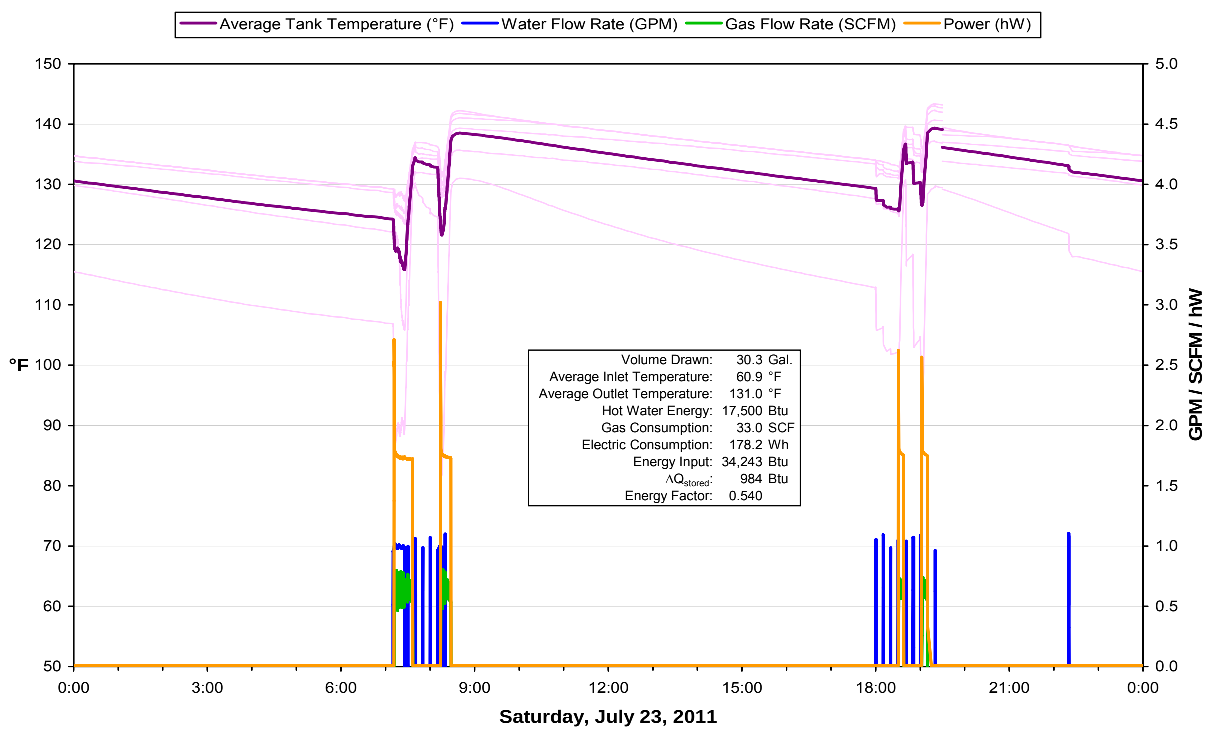
AO Smith GPVR-40
GTI Low Use Draw Profile

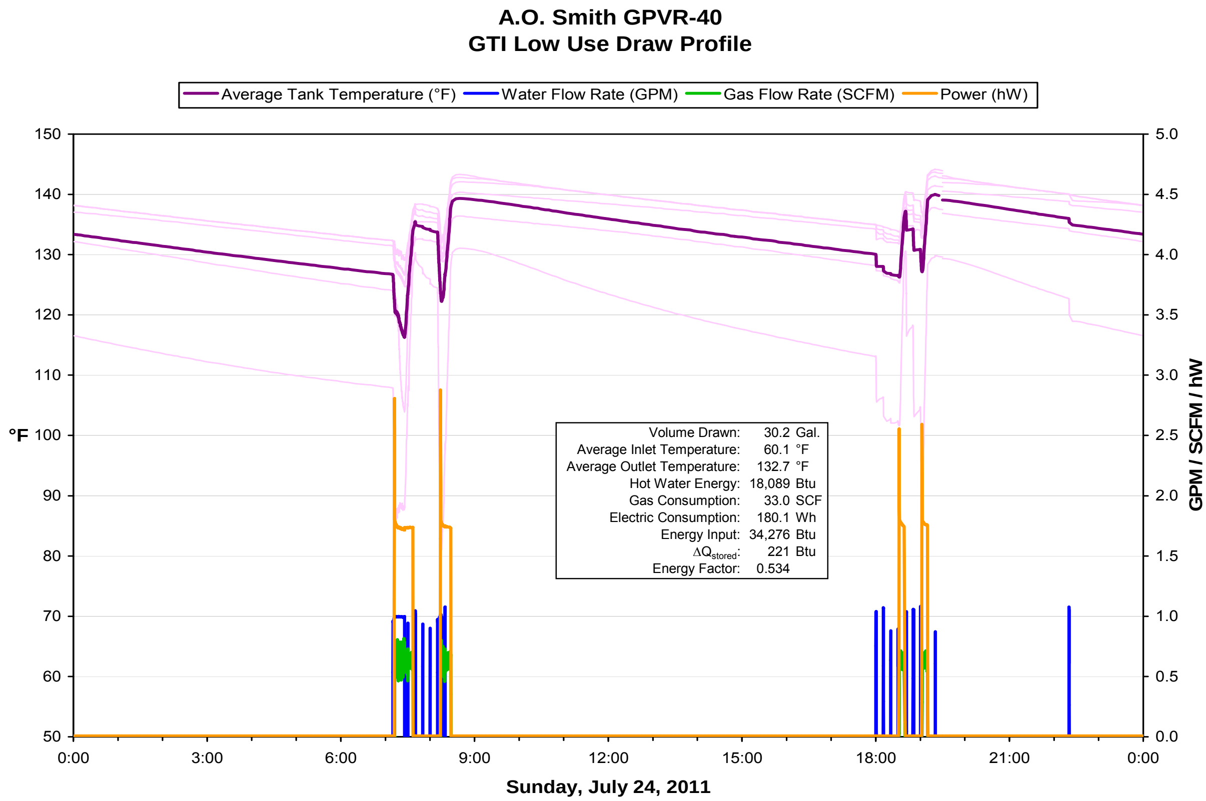


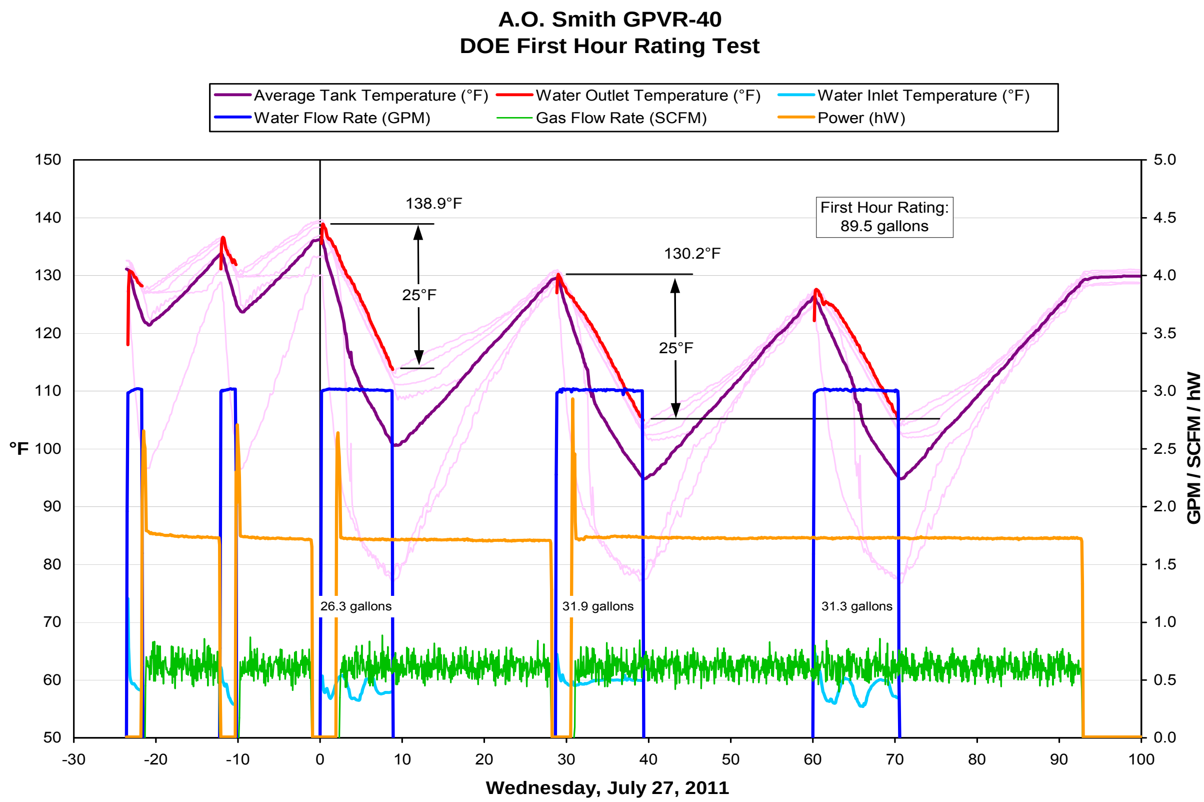
AO Smith GPVR40
GTI Low Use Draw Profile



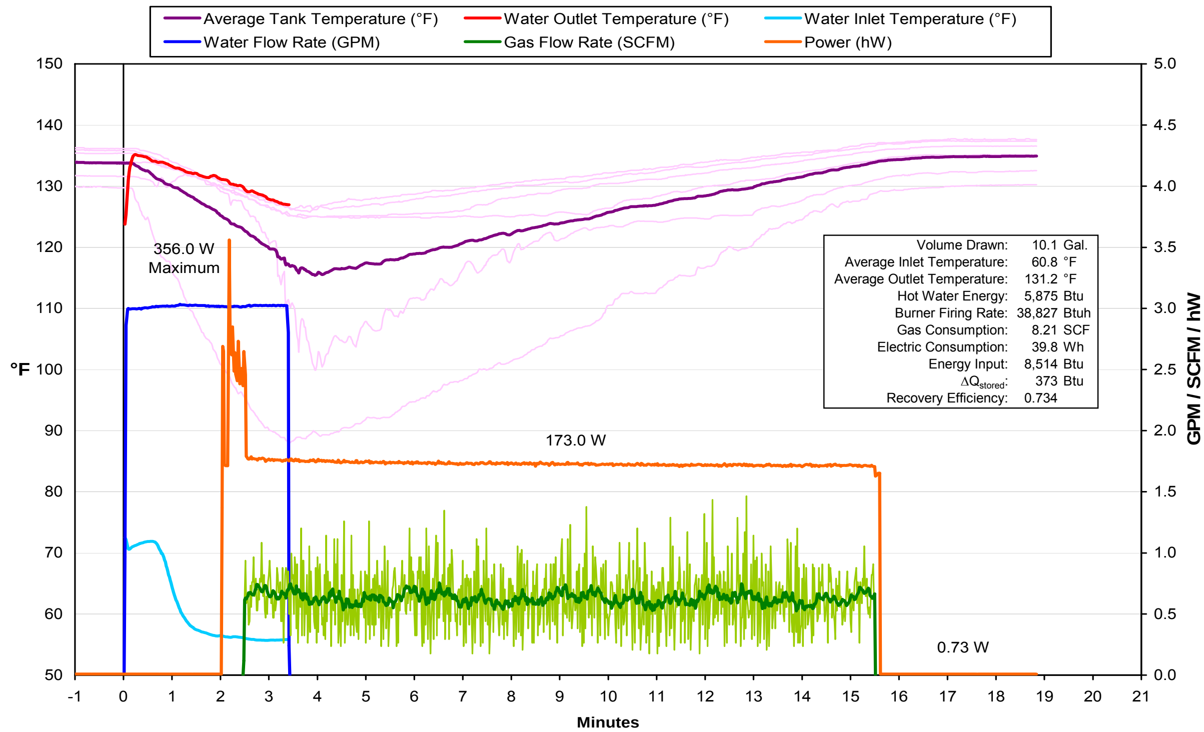
A.O. Smith GPVR-40
GTI Low Use Draw Profile



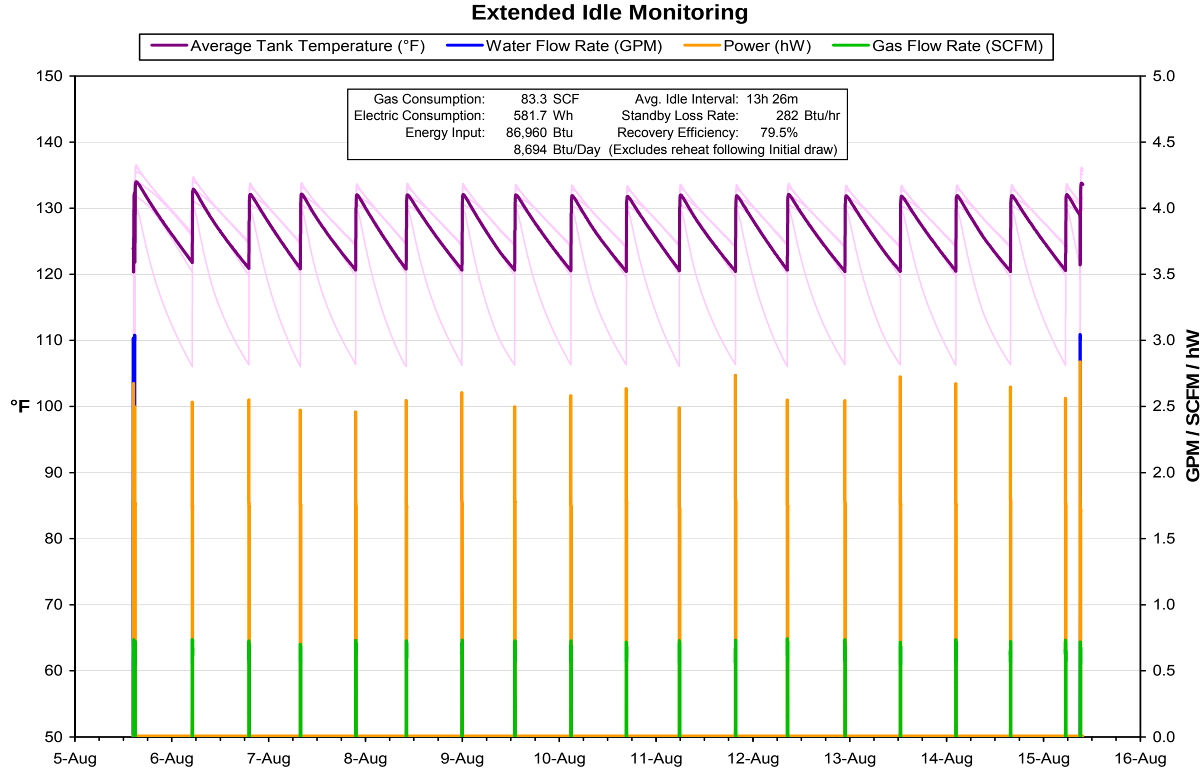

A.O. Smith GPVR-40
GTI Low Use Draw Profile
Average Tank Temperature (°F)
Water Flow Rate (GPM)
Gas Flow Rate (SCFM)
Power (hW)
°F
GPM / SCFM / hW
Volume Drawn: 30.2 Gal.
Average Inlet Temperature: 60.1 °F
Average Outlet Temperature: 132.7 °F
Hot Water Energy: 18,089 Btu
Gas Consumption: 33.0 SCF
Electric Consumption: 180.1 Wh
Energy Input: 34,276 Btu
ΔQ_{stored}: 221 Btu
Energy Factor: 0.534
Sunday, July 24, 2011


A.O. Smith GPVR-40
DOE First Hour Rating Test
Average Tank Temperature (°F)
Water Outlet Temperature (°F)
Water Inlet Temperature (°F)
Water Flow Rate (GPM)
Gas Flow Rate (SCFM)
Power (hW)
°F
GPM / SCFM / hW
138.9°F
25°F
130.2°F
25°F
First Hour Rating:
89.5 gallons
26.3 gallons
31.9 gallons
31.3 gallons
Wednesday, July 27, 2011

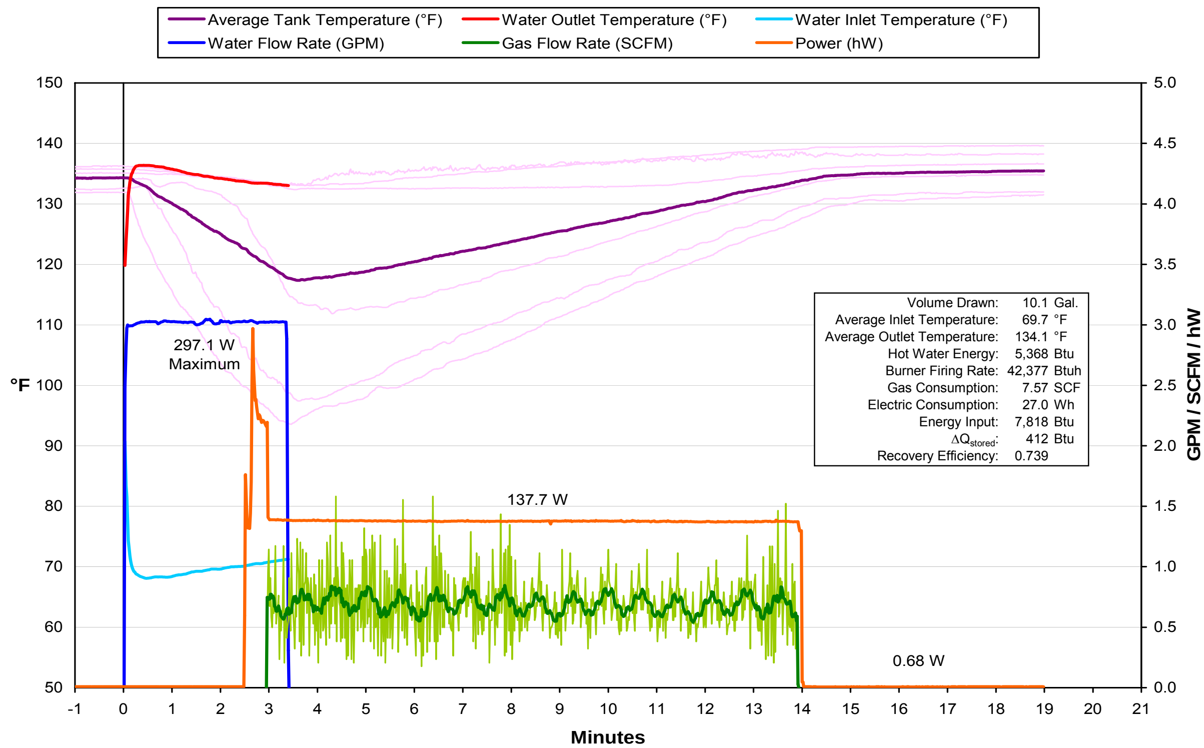
A.O. Smith GPVR-40
Power Consumption Detail
(1 second scan rate)



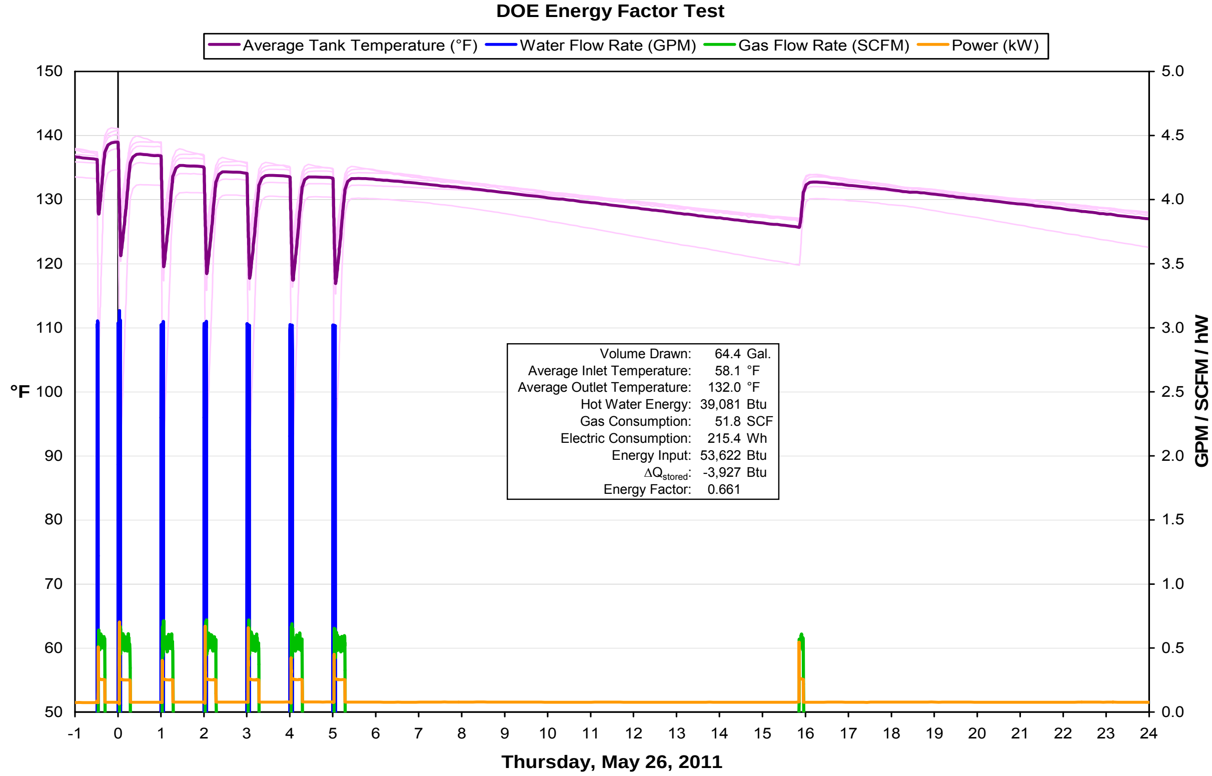
A.O. Smith GPVR-40
Extended Idle Monitoring



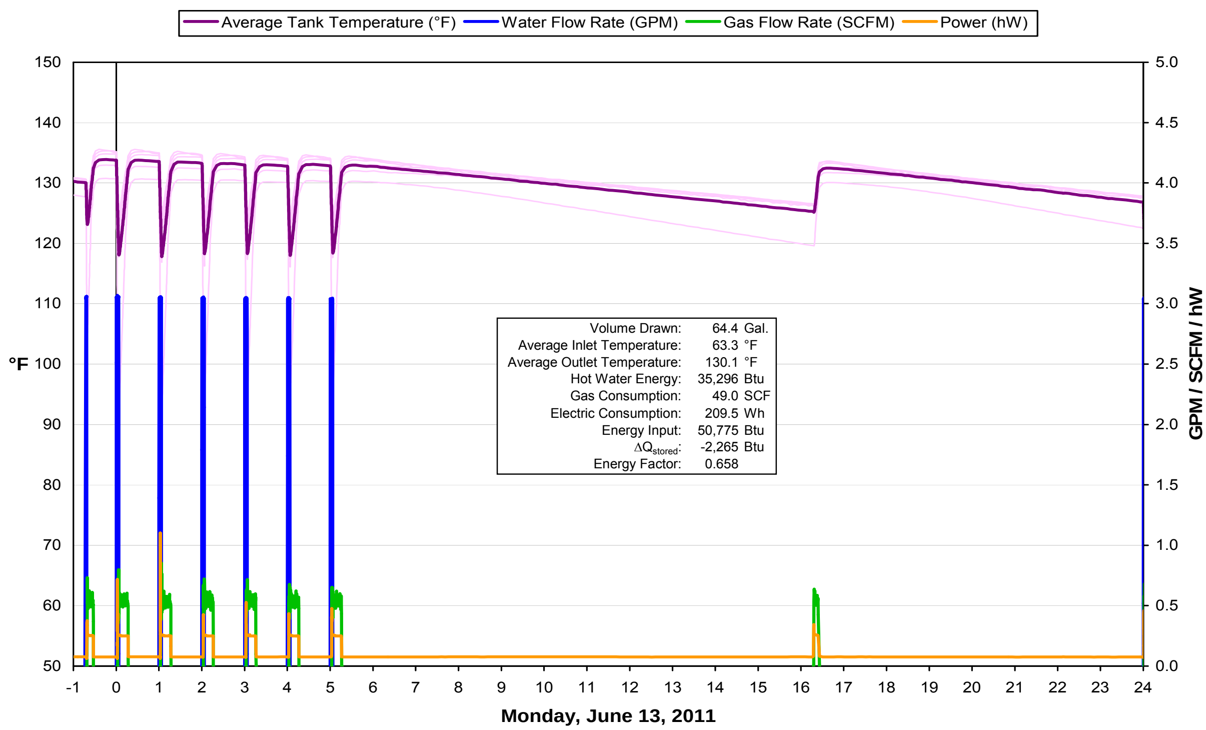
Rheem PDV-40



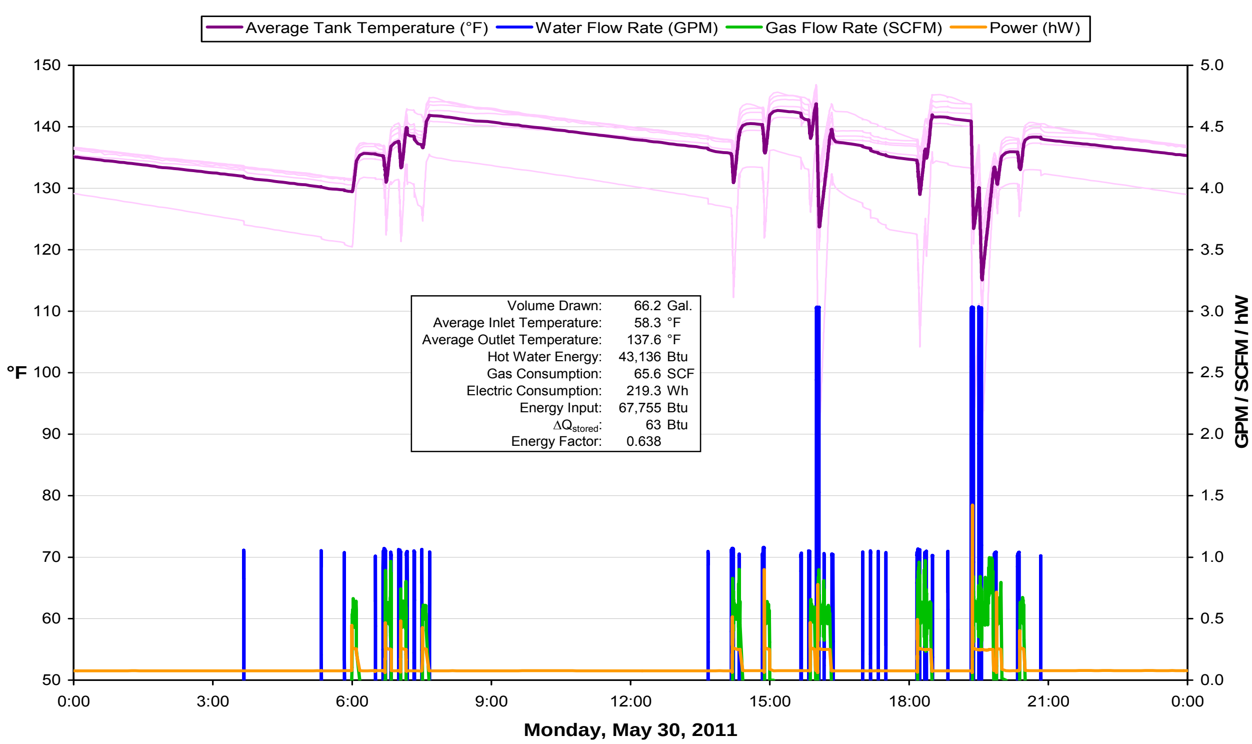
AO Smith Effex GAHH-40
DOE Energy Factor Test

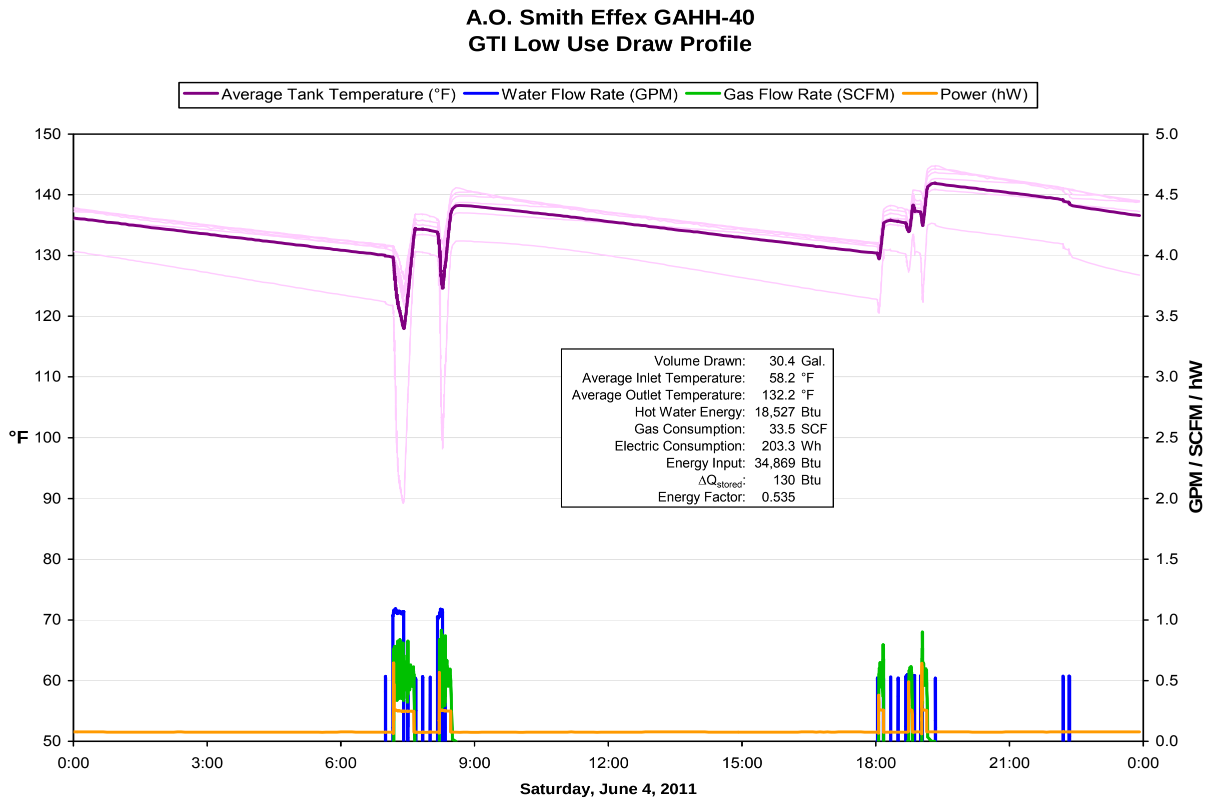


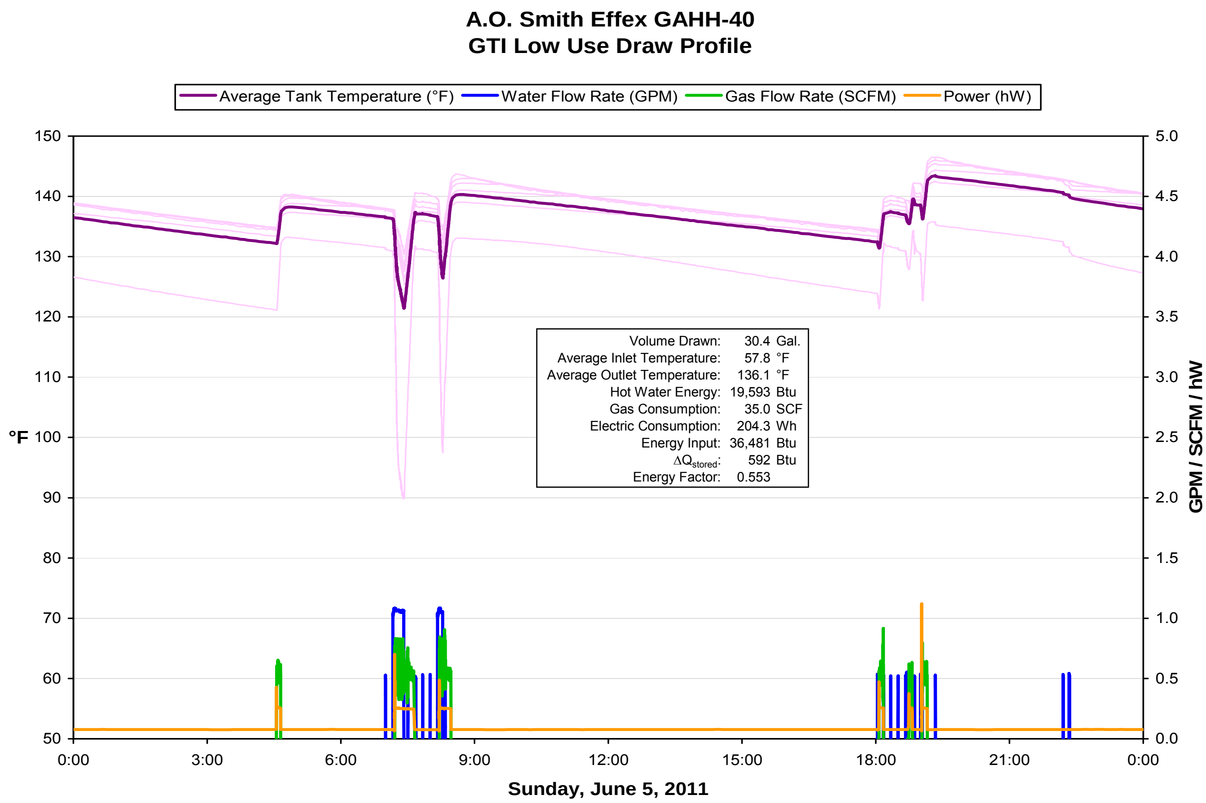
A.O. Smith Effex GAHH-40
DOE Energy Factor Test



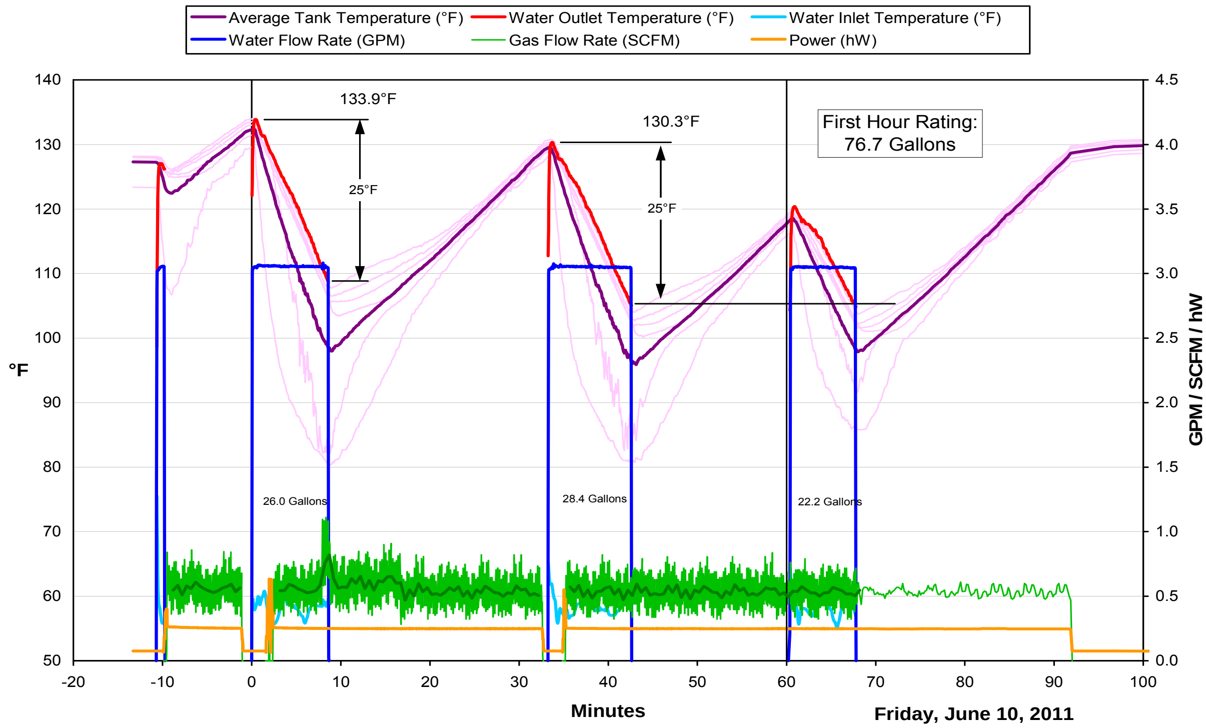
A.O. Smith Effex GAHH-40
GTI Medium Use Draw Pattern



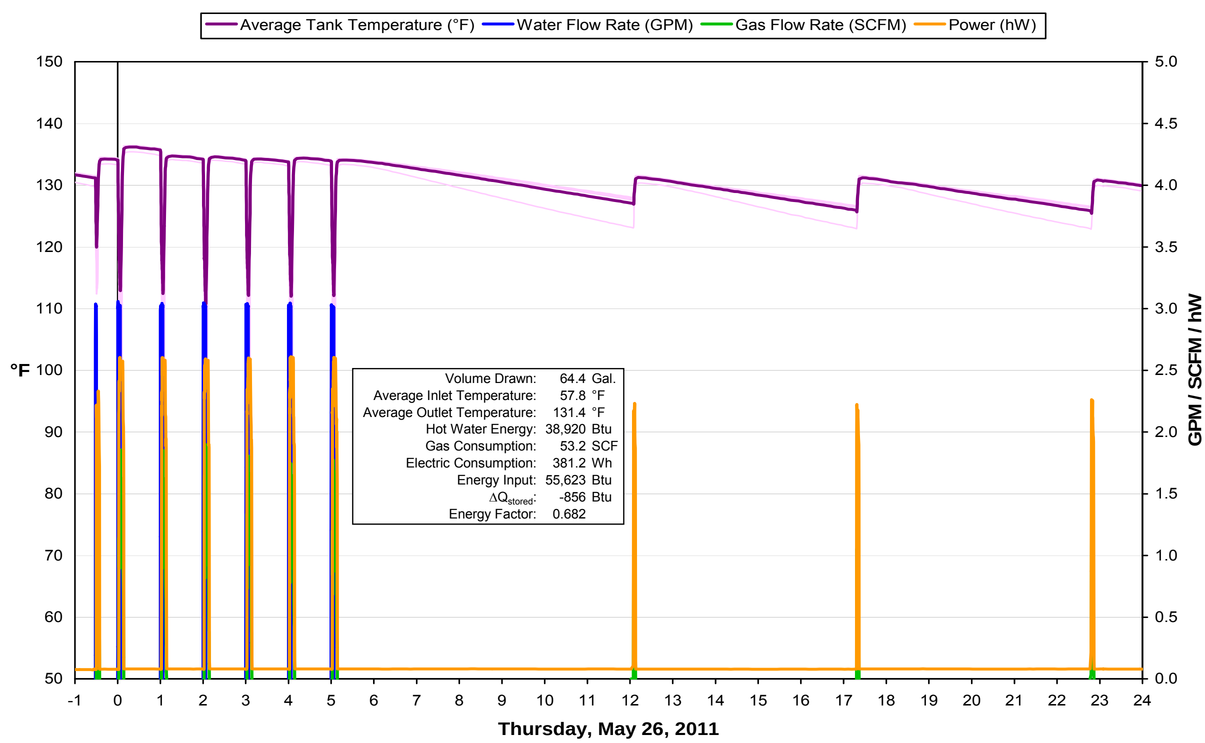

A.O. Smith Effex GAHH-40
GTI Low Use Draw Profile
Average Tank Temperature (°F)
Water Flow Rate (GPM)
Gas Flow Rate (SCFM)
Power (hW)
°F
GPM / SCFM / hW
Volume Drawn: 30.4 Gal.
Average Inlet Temperature: 58.2 °F
Average Outlet Temperature: 132.2 °F
Hot Water Energy: 18,527 Btu
Gas Consumption: 33.5 SCF
Electric Consumption: 203.3 Wh
Energy Input: 34,869 Btu
ΔQstored: 130 Btu
Energy Factor: 0.535
Saturday, June 4, 2011

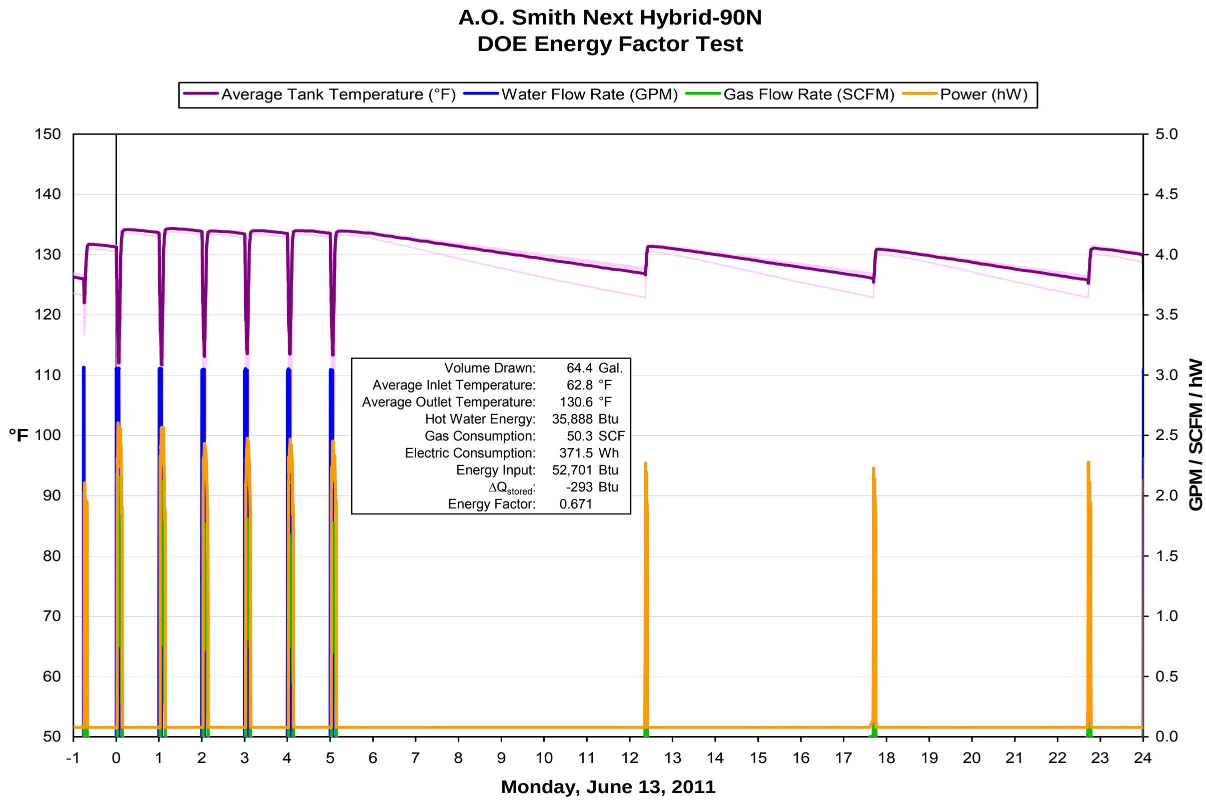

A.O. Smith Effex GAHH-40
GTI Low Use Draw Profile
Average Tank Temperature (°F)
Water Flow Rate (GPM)
Gas Flow Rate (SCFM)
Power (hW)
°F
GPM / SCFM / hW
Volume Drawn: 30.4 Gal.
Average Inlet Temperature: 57.8 °F
Average Outlet Temperature: 136.1 °F
Hot Water Energy: 19,593 Btu
Gas Consumption: 35.0 SCF
Electric Consumption: 204.3 Wh
Energy Input: 36,481 Btu
ΔQstored: 592 Btu
Energy Factor: 0.553
Sunday, June 5, 2011

A.O. Smith Effex GAHH-40
First Hour Rating Test

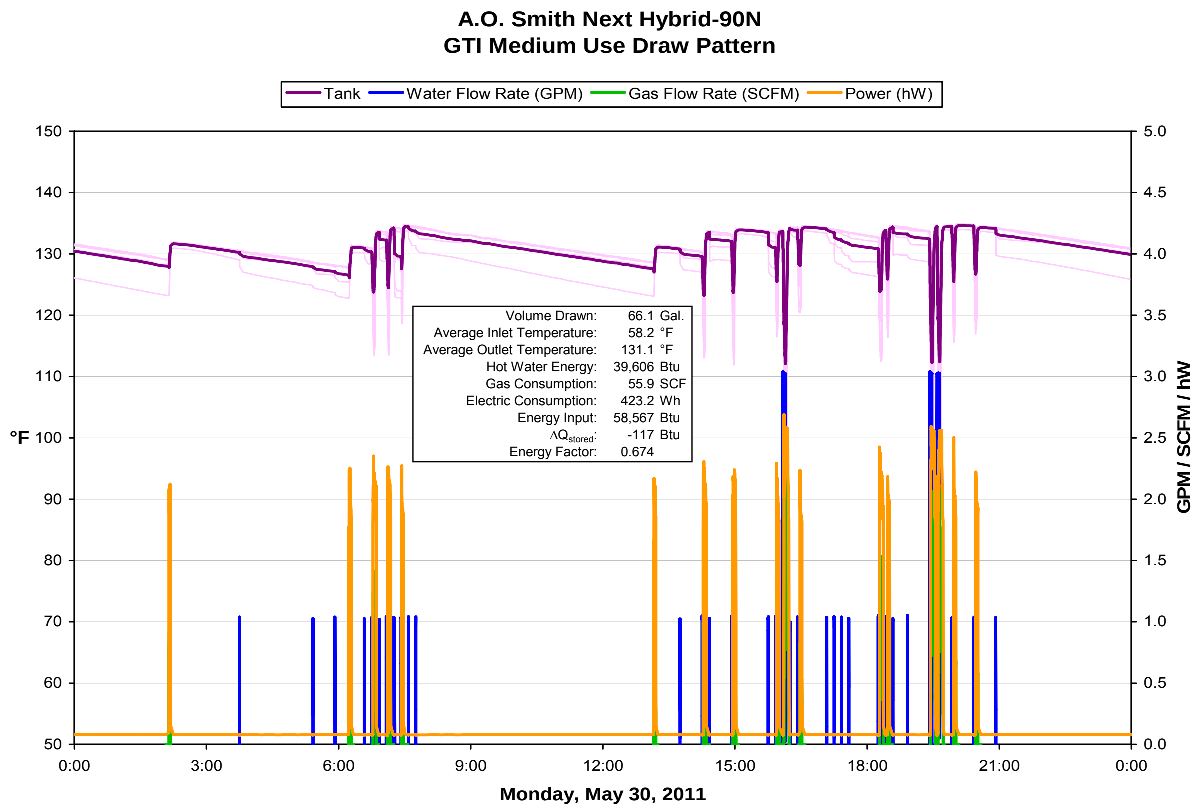


AO Smith Next Hybrid-90N
DOE Energy Factor Test



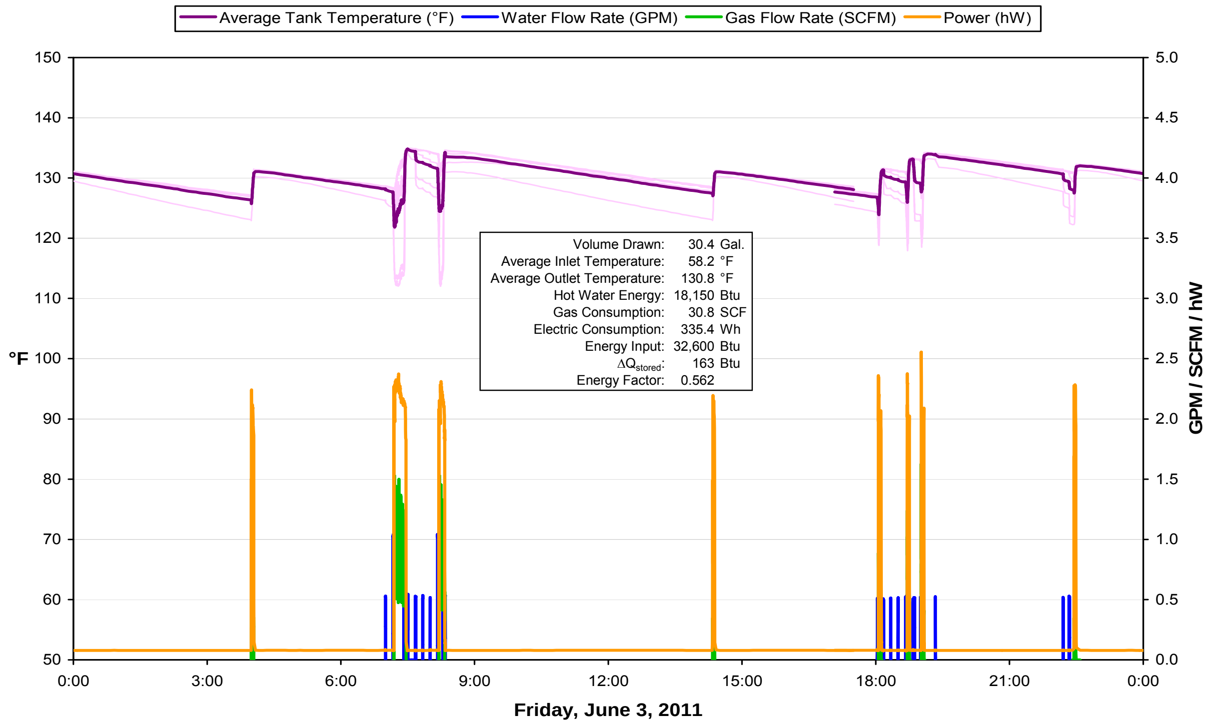


A.O. Smith Next Hybrid-90N
DOE Energy Factor Test
Average Tank Temperature (°F)
Water Flow Rate (GPM)
Gas Flow Rate (SCFM)
Power (hW)
Volume Drawn: 64.4 Gal.
Average Inlet Temperature: 62.8 °F
Average Outlet Temperature: 130.6 °F
Hot Water Energy: 35,888 Btu
Gas Consumption: 50.3 SCF
Electric Consumption: 371.5 Wh
Energy Input: 52,701 Btu
ΔQ_{stored}: -293 Btu
Energy Factor: 0.671
°F
GPM / SCFM / hW
Monday, June 13, 2011

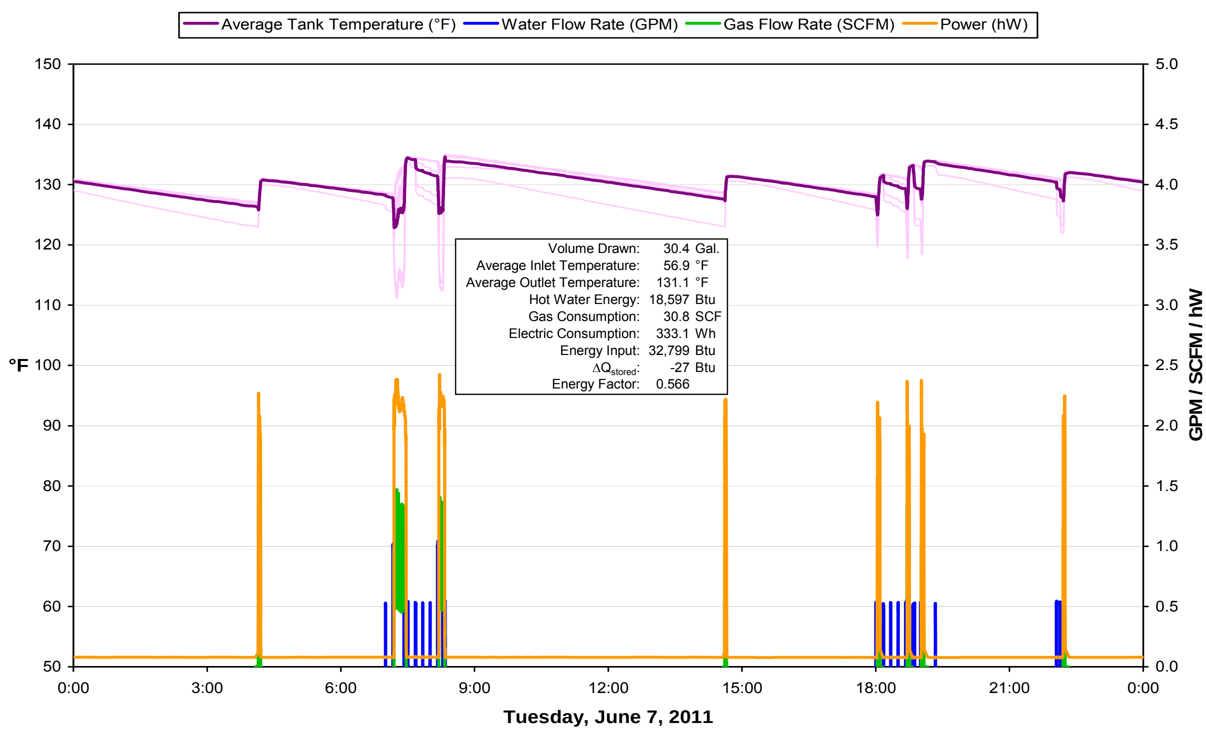


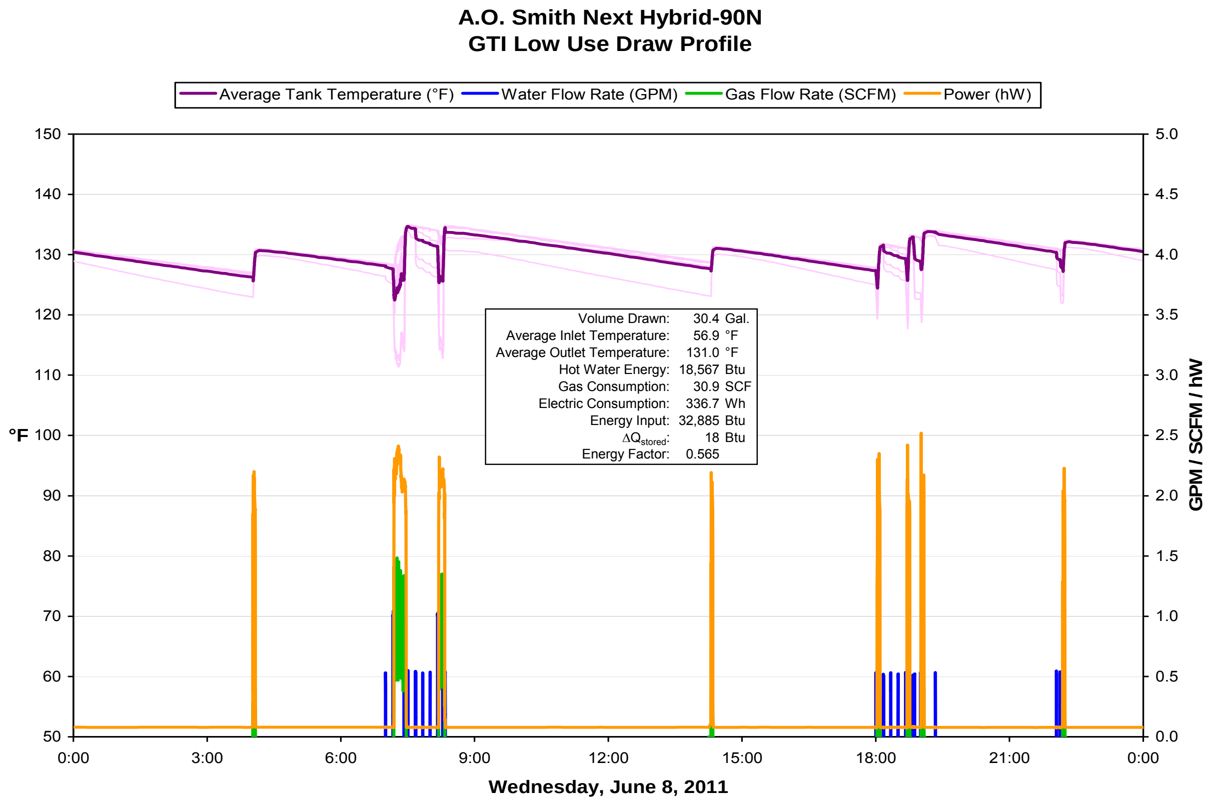
A.O. Smith Next Hybrid-90N
GTI Medium Use Draw Pattern
Tank
Water Flow Rate (GPM)
Gas Flow Rate (SCFM)
Power (hW)
Volume Drawn: 66.1 Gal.
Average Inlet Temperature: 58.2 °F
Average Outlet Temperature: 131.1 °F
Hot Water Energy: 39,606 Btu
Gas Consumption: 55.9 SCF
Electric Consumption: 423.2 Wh
Energy Input: 58,567 Btu
ΔQstored: -117 Btu
Energy Factor: 0.674
°F
GPM / SCFM / hW
Monday, May 30, 2011

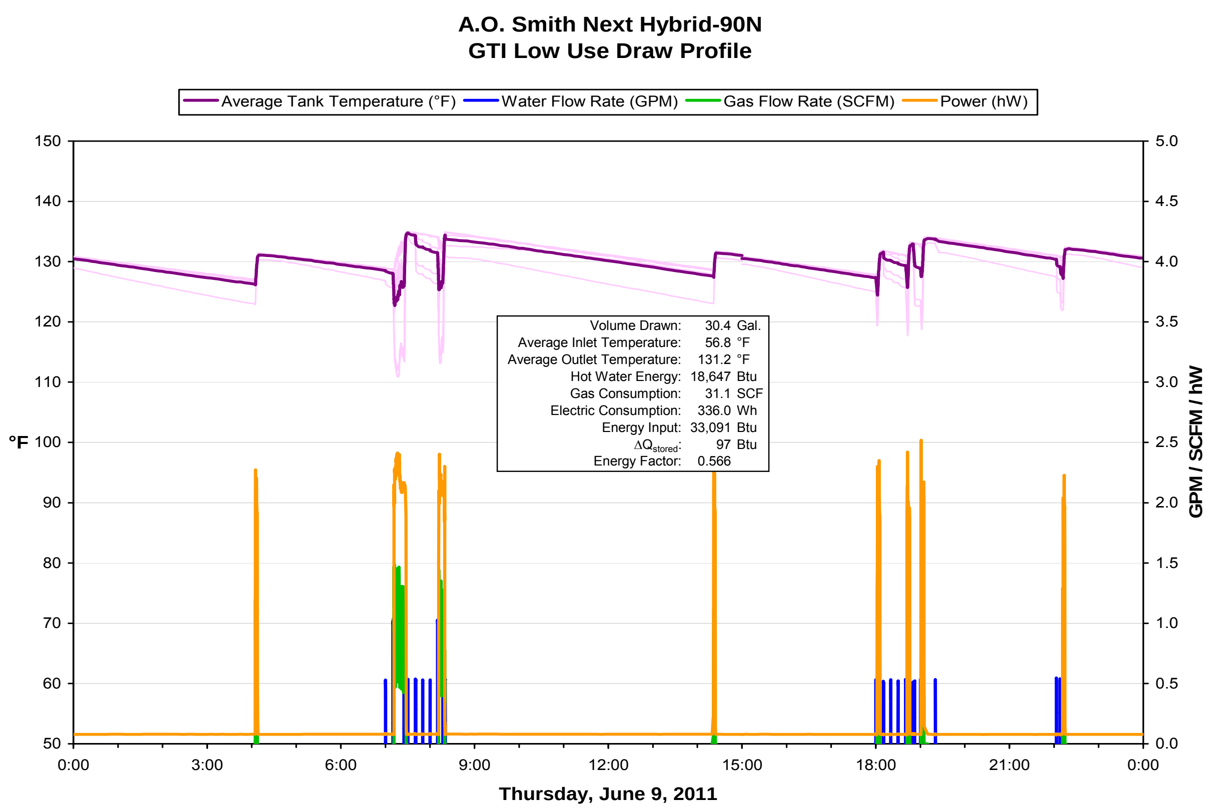
A.O. Smith Next Hybrid-90N
GTI Low Use Draw Pattern

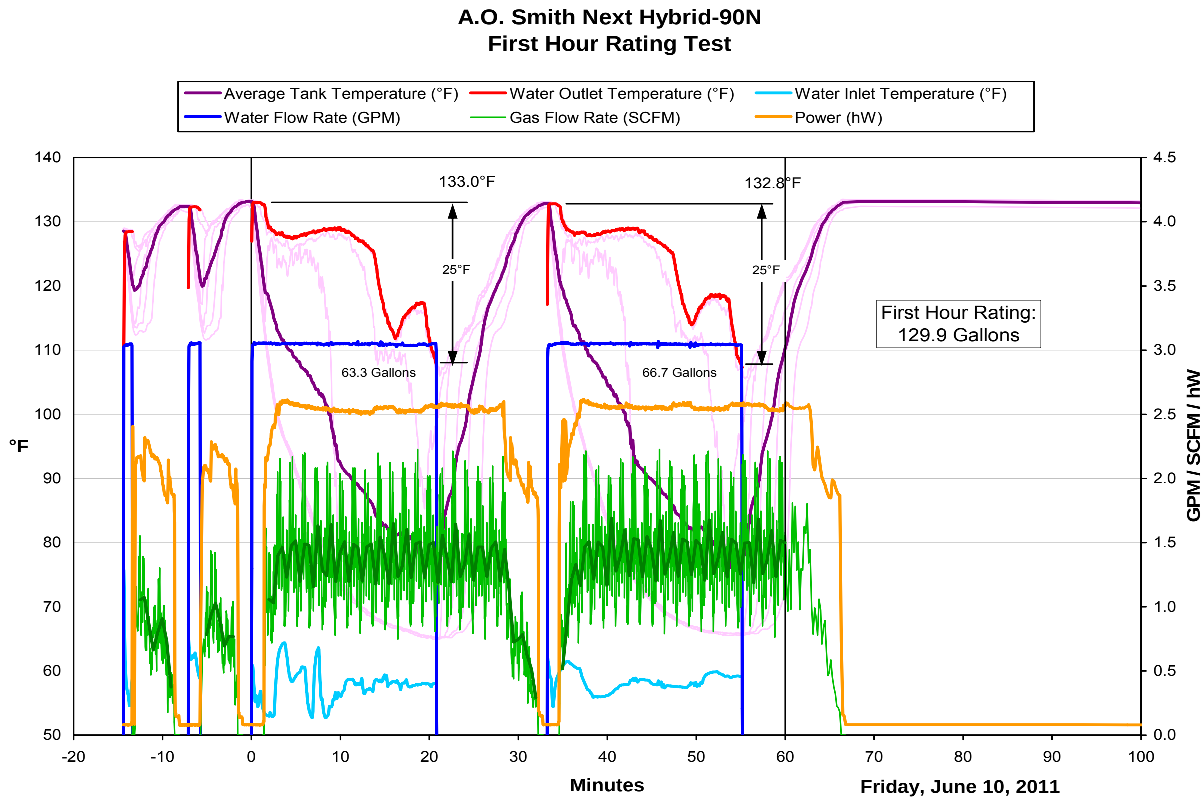


A.O. Smith Next Hybrid-90N
GTI Low Use Draw Profile

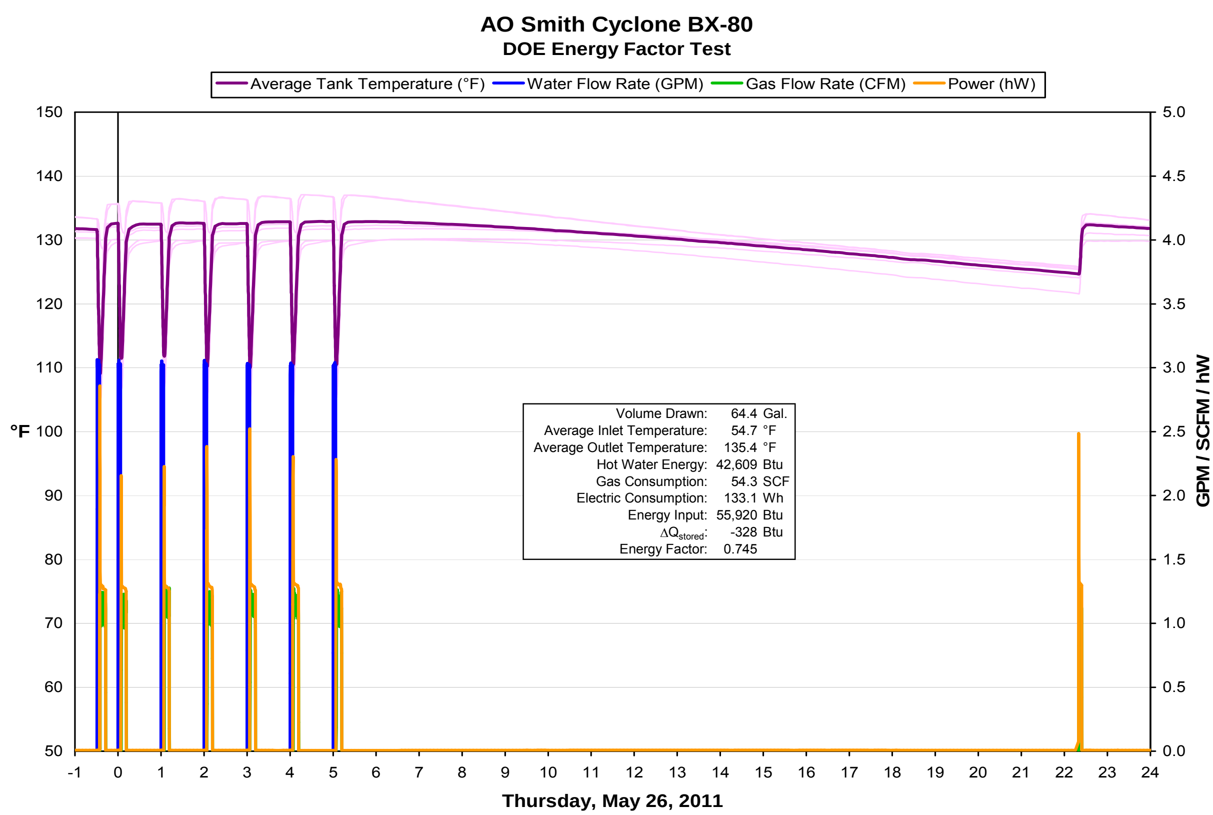



A.O. Smith Next Hybrid-90N
GTI Low Use Draw Profile
Average Tank Temperature (°F)
Water Flow Rate (GPM)
Gas Flow Rate (SCFM)
Power (hW)
°F
GPM / SCFM / hW
Volume Drawn: 30.4 Gal.
Average Inlet Temperature: 56.9 °F
Average Outlet Temperature: 131.0 °F
Hot Water Energy: 18,567 Btu
Gas Consumption: 30.9 SCF
Electric Consumption: 336.7 Wh
Energy Input: 32,885 Btu
ΔQ_{stored}: 18 Btu
Energy Factor: 0.565
Wednesday, June 8, 2011

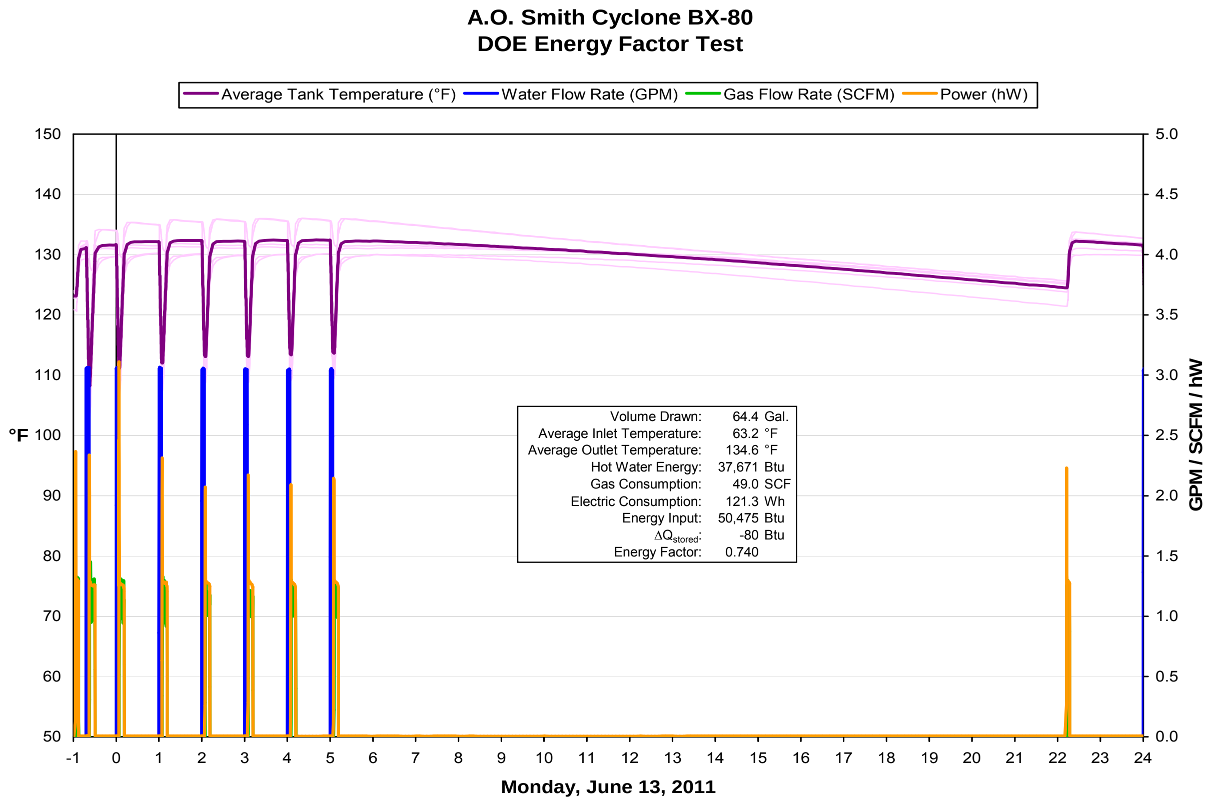

A.O. Smith Next Hybrid-90N
GTI Low Use Draw Profile
Average Tank Temperature (°F)
Water Flow Rate (GPM)
Gas Flow Rate (SCFM)
Power (hW)
°F
GPM / SCFM / hW
Volume Drawn: 30.4 Gal.
Average Inlet Temperature: 56.8 °F
Average Outlet Temperature: 131.2 °F
Hot Water Energy: 18,647 Btu
Gas Consumption: 31.1 SCF
Electric Consumption: 336.0 Wh
Energy Input: 33,091 Btu
ΔQ_{stored}: 97 Btu
Energy Factor: 0.566
Thursday, June 9, 2011

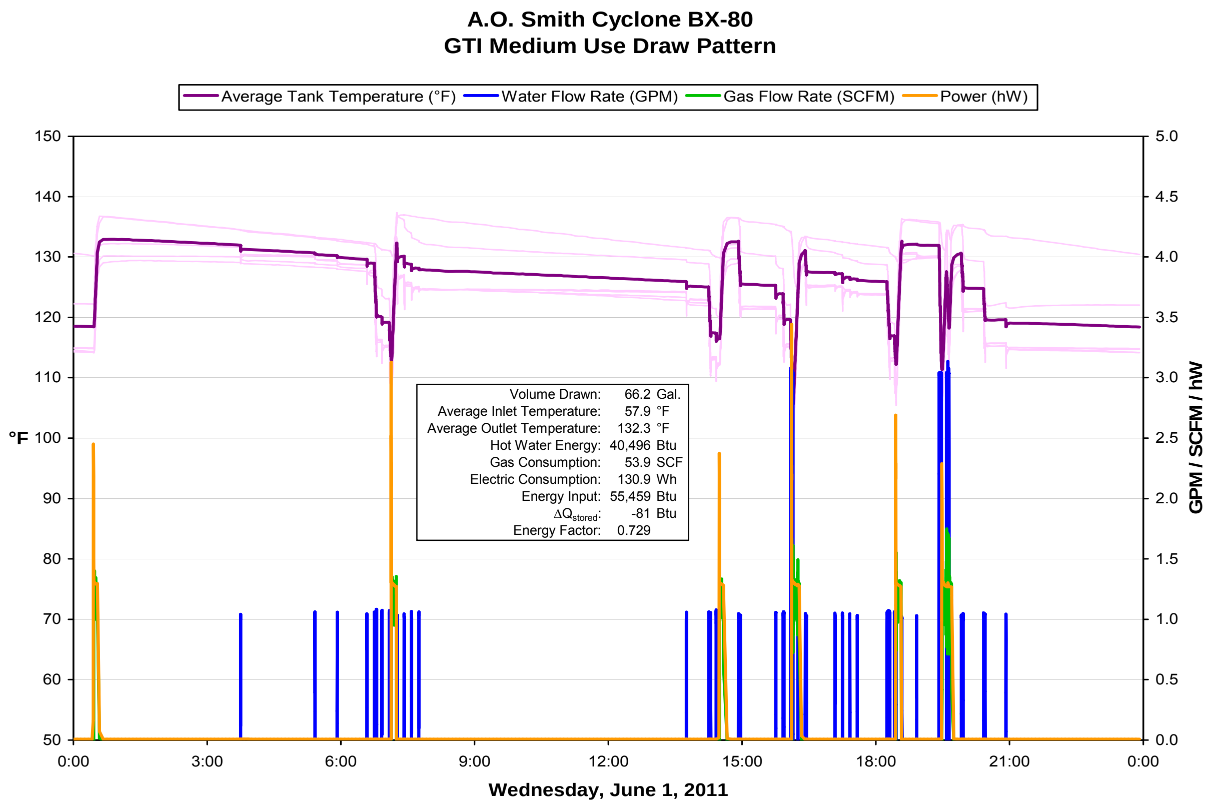


A.O. Smith Next Hybrid-90N
First Hour Rating Test
Average Tank Temperature (°F)
Water Outlet Temperature (°F)
Water Inlet Temperature (°F)
Water Flow Rate (GPM)
Gas Flow Rate (SCFM)
Power (hW)
133.0°F
132.8°F
25°F
25°F
63.3 Gallons
66.7 Gallons
First Hour Rating:
129.9 Gallons
°F
GPM / SCFM / hW
Minutes
Friday, June 10, 2011

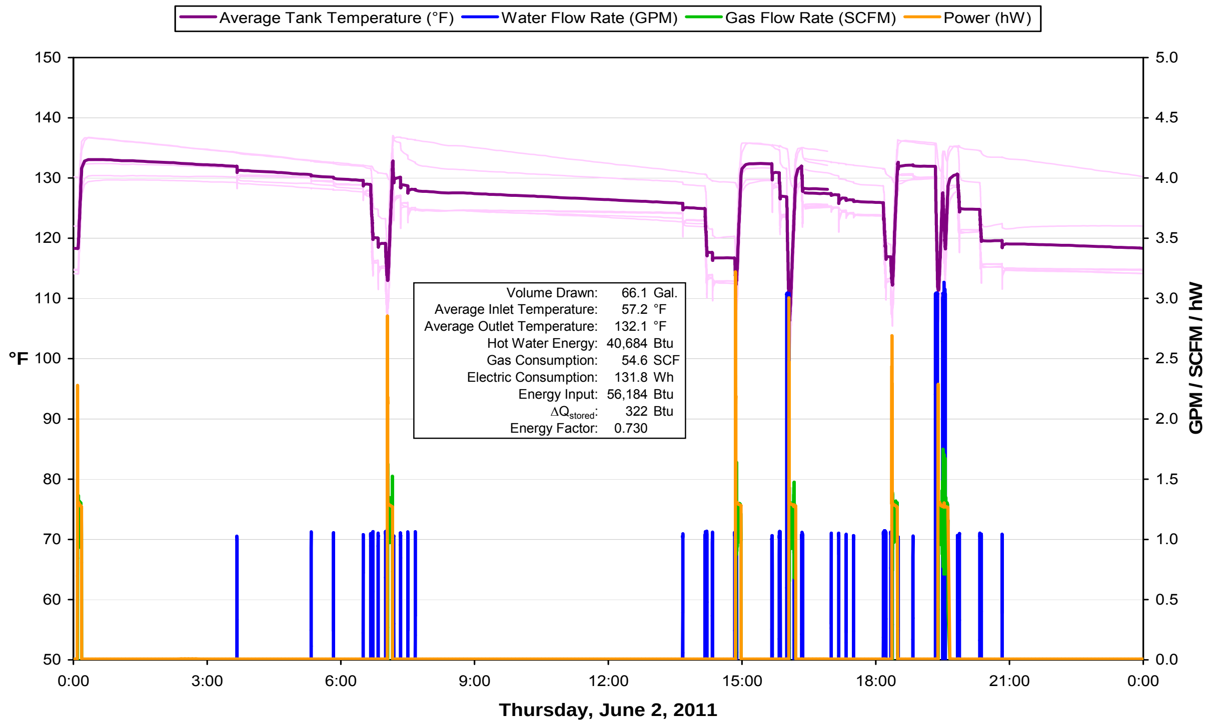


AO Smith Cyclone BX-80
DOE Energy Factor Test
Average Tank Temperature (°F)
Water Flow Rate (GPM)
Gas Flow Rate (CFM)
Power (hW)
Volume Drawn: 64.4 Gal.
Average Inlet Temperature: 54.7 °F
Average Outlet Temperature: 135.4 °F
Hot Water Energy: 42,609 Btu
Gas Consumption: 54.3 SCF
Electric Consumption: 133.1 Wh
Energy Input: 55,920 Btu
ΔQstored: -328 Btu
Energy Factor: 0.745
°F
GPM / SCFM / hW
Thursday, May 26, 2011

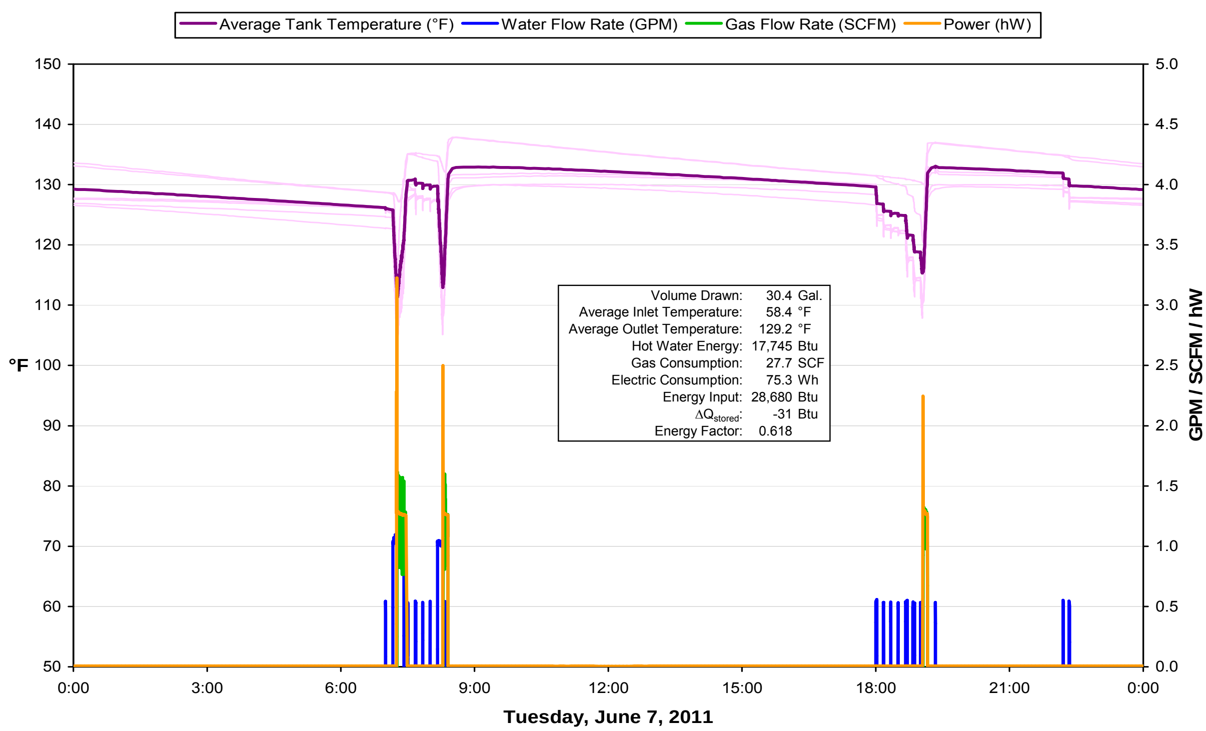

A.O. Smith Cyclone BX-80
DOE Energy Factor Test
Average Tank Temperature (°F)
Water Flow Rate (GPM)
Gas Flow Rate (SCFM)
Power (hW)
°F
GPM / SCFM / hW
Volume Drawn: 64.4 Gal.
Average Inlet Temperature: 63.2 °F
Average Outlet Temperature: 134.6 °F
Hot Water Energy: 37,671 Btu
Gas Consumption: 49.0 SCF
Electric Consumption: 121.3 Wh
Energy Input: 50,475 Btu
ΔQ_{stored}: -80 Btu
Energy Factor: 0.740
Monday, June 13, 2011

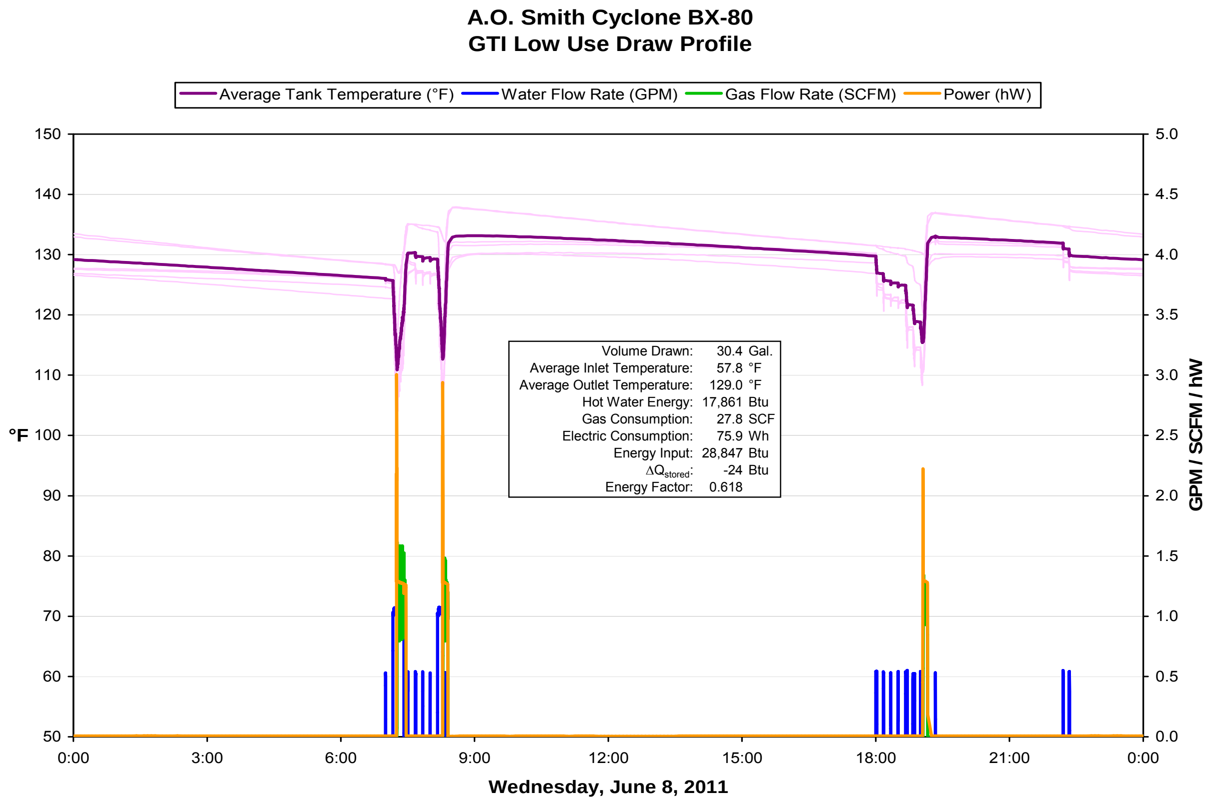

A.O. Smith Cyclone BX-80
GTI Medium Use Draw Pattern
Average Tank Temperature (°F)
Water Flow Rate (GPM)
Gas Flow Rate (SCFM)
Power (hW)
°F
GPM / SCFM / hW
Volume Drawn: 66.2 Gal.
Average Inlet Temperature: 57.9 °F
Average Outlet Temperature: 132.3 °F
Hot Water Energy: 40,496 Btu
Gas Consumption: 53.9 SCF
Electric Consumption: 130.9 Wh
Energy Input: 55,459 Btu
ΔQ_{stored}: -81 Btu
Energy Factor: 0.729
Wednesday, June 1, 2011

A.O. Smith Cyclone BX-80
GTI Medium Use Draw Pattern

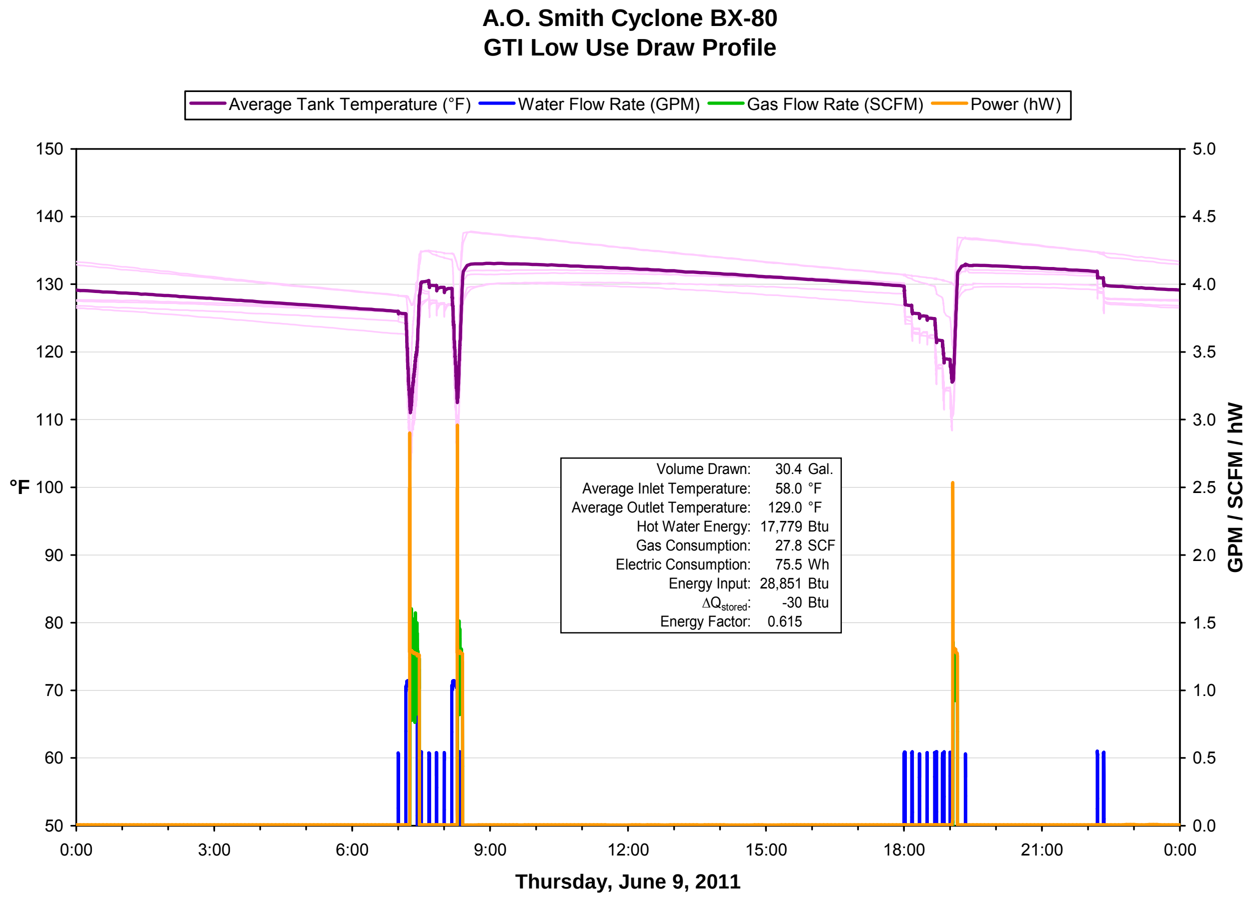


A.O. Smith Cyclone BX-80
GTI Low Use Draw Profile





A.O. Smith Cyclone BX-80
GTI Low Use Draw Profile
Average Tank Temperature (°F)
Water Flow Rate (GPM)
Gas Flow Rate (SCFM)
Power (hW)
Volume Drawn: 30.4 Gal.
Average Inlet Temperature: 57.8 °F
Average Outlet Temperature: 129.0 °F
Hot Water Energy: 17,861 Btu
Gas Consumption: 27.8 SCF
Electric Consumption: 75.9 Wh
Energy Input: 28,847 Btu
ΔQstored: -24 Btu
Energy Factor: 0.618
°F
GPM / SCFM / hW
Wednesday, June 8, 2011


A.O. Smith Cyclone BX-80
GTI Low Use Draw Profile
Average Tank Temperature (°F)
Water Flow Rate (GPM)
Gas Flow Rate (SCFM)
Power (hW)
°F
GPM / SCFM / hW
Volume Drawn: 30.4 Gal.
Average Inlet Temperature: 58.0 °F
Average Outlet Temperature: 129.0 °F
Hot Water Energy: 17,779 Btu
Gas Consumption: 27.8 SCF
Electric Consumption: 75.5 Wh
Energy Input: 28,851 Btu
ΔQstored: -30 Btu
Energy Factor: 0.615
Thursday, June 9, 2011

Appendix J: Tankless Water Heater Laboratory Tests Full Tabular and Graphical Datasets

Figure 21: Non-Condensing TWH

Figure 22: Condensing 1 TWH

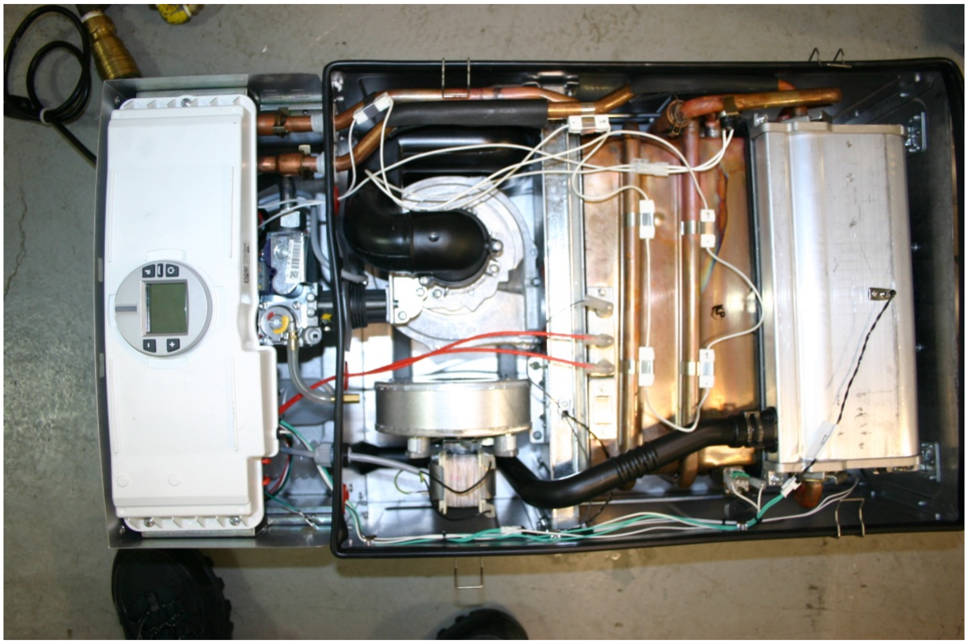


Figure 23: Condensing 2 TWH

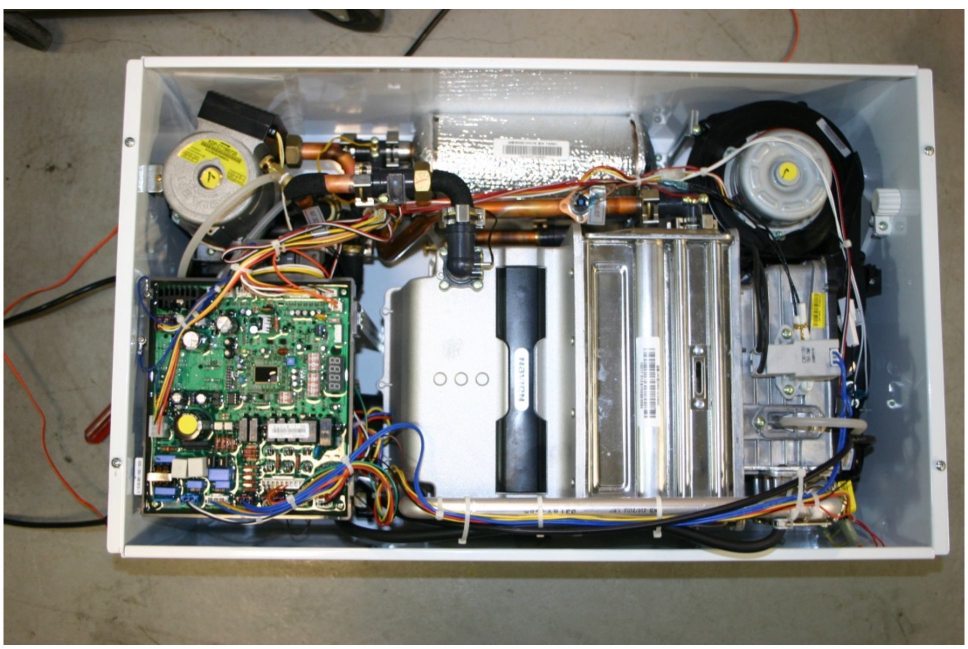


Figure 24: Condensing with Buffer Tank TWH

Thermal Capacitance & UA Testing

Table 28 summarizes the results of the Quick Thermal Capacitance Test, with the 0 duration standby period repeated. The average C and UA are 6.6 Btu/°F and 36.9 (Btu/hr)/°F respectively, or 12.6 kJ/°C and 19.5 W/°C within the range of the values estimated by Burch et al [**Error! Reference source not found.**] 9.5 kJ/°C and 13 W/°C respectively.

Table 28: Summary of Results for Thermal Capacitance/UA of Non-Condensing TWH

	Gap Time (min)	**Avg C** Btu/°F	**Avg UA** (Btu/hr)/°F	**Heat Withdrawn During Draw Down** (Btus)	**Standby Heat Loss** (Btus)
Draw 1	0	6.5	41.6	256.6	0
Draw 2	0	6.7	38.8	248.4	0
Draw 3	22.5	6.9	41.5	170.0	82.5
Draw 4	45.0	6.3	25.8	133.1	119.3
Average		**6.6**	**36.9**		

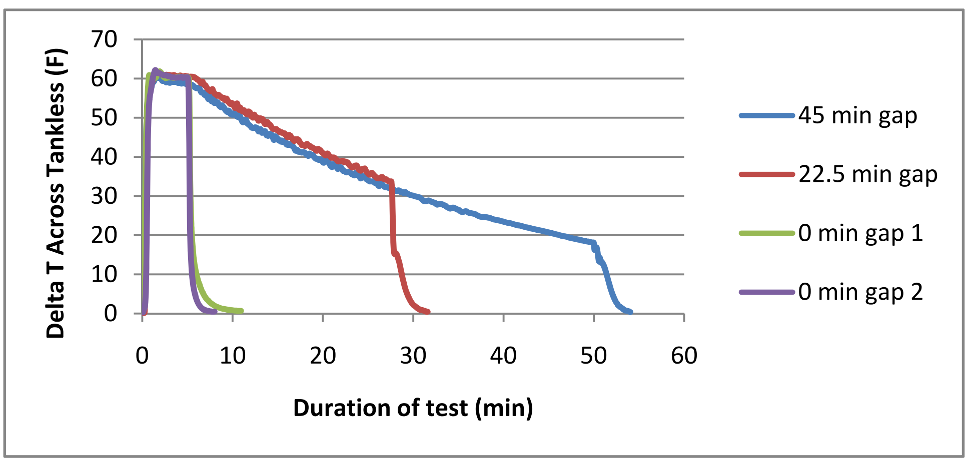


Figure 25: Temperature Plot over Thermal Capacitance Testing for Non-Condensing TWH

For focused UA testing, an alternative approach to determine the UA is to supply heated water to the unit from an external source, and run it at a steady state condition with the power off and a low water volume. Under this scenario, the left-hand side of the 'Steady State' equation is zero, with no thermal input from combustion:

Equation 41: Steady State

$$0 = \dot{m}C_P\left(T - T_{in}\right) + UA\left(T - T_{env}\right)$$

When calculating the UA using this method, the volumetric air flow must be known. This was calculated by measuring the excess oxygen and flue gas temperature, in conjunction with a GTI natural gas analysis which yields the higher heating value of the fuel and fuel speciation (CH_4, C_2H_6, etc.). At a 130°F setpoint (inlet 70°F) and water flow rate of 3.0 gpm, excess aeration was an average of 9.56% O_2 (dry) and a flue temperature of 176°F. The burners are firing at approximately 108,000 Btu/hr. At this operating point, the two-stage blower is operating in the "low" stage. Under these conditions for the non-condensing unit and the fuel analysis, the volumetric air-to-fuel ratio (16.7), moisture content (0.078 lb H_2O/lb dry flue gas), and psychrometric properties are calculated (approximating flue gases as moist air).

Equation 42: Efficiency Definitions

$$\eta_{comb} = \frac{Q_{Gas} - Q_{FG}}{Q_{Gas}}\text{; } \eta_{Th} = \frac{Q_{Water}}{Q_{Gas}}$$

With these calculations, the volumetric air flow on the low blower setting is estimated at 1,840 scf/hr, scf/hr, the combustion efficiency is 86.7%, and the thermal efficiency is 85.5%. The flue gas has an an estimated dew point of 118.6°F and a heat content of 14,300 Btu/hr. The results of this alternative alternative approach, are within the range of the values estimated by Burch et al., and within the range the range of the values from the Quick Thermal Capacitance Test. Note that the results with the blower on, approximately 32 Btu/hr-°F, are consistent with the average from earlier general testing of testing of 36.9 Btu/hr-°F. Thus, for future determination of the UA value where fixed operation of the of the blower independent of firing may prove difficult, reasonably accurate results for a "blower on "blower on UA" may be derived from either the combined testing in Table 28 or the Focused UA Testing. This "blower on UA" depends on many variables, primarily the blower staging and air-to-fuel ratio (or stack O_2), which will vary over the range of operating conditions. The excess aeration will be measured for "high" stage blower operation and additional rows will be filled in Table 3 for high blower speed operation. The "blower off UA", at 8 Btu/hr-°F, represents the infinitely long standby period case in

Table 29. The results are shown for the condensing TWH in Table 30, however the unit did not have a feature whereby the combustion air blower could be activated without firing, thus only blower off tests were run. Blower on UA and thermal capacitance calculations were estimated from 24 Hour datasets, using the ramp-up equation and 1 second sampling.

Table 29: Alternative UA Test Results for Non-Condensing TWH

Input Temperature (°F)	Fan Speed	Water Flow Rate (gpm)	UA			Q water (Btu/hr)	Q Air (Flue) (Btu/hr)	Residual %
			Water (Btu/hr-°F)	Air (Btu/hr-°F)	Average (Btu/hr-°F)			
130	Low	1.0	30.4	33.4	32.0	1,985	1,848	6.9
150	Low	1.0	29.5	34.0	31.8	2,437	2,181	10.5
150	Off	1.0	8.0	N/A	8.0	662	N/A	N/A

Table 30: Alternative UA Test Results for Condensing 1 TWH

Input Temperature (°F)	Fan Speed	Water Flow Rate (gpm)	UA			Q water (Btu/hr)	Q Air (Flue) (Btu/hr)	Residual %
			Water (Btu/hr-°F)	Air (Btu/hr-°F)	Average (Btu/hr-°F)			
130	Off	1.0	8.7	N/A	N/A	479	N/A	N/A
150	Off	1.0	7.3	N/A	N/A	531	N/A	N/A

Over the course of tests, the water side pressure drop was measured for all TWHs over a range of flow rates. All mass flow vs. pressure drop curves form a good fit to a 2nd order polynomial of:

Equation 43: Mass Flow v. Pressure Drop Curve

$\boldsymbol{\Delta P} = \boldsymbol{A}(\dot{\boldsymbol{m}})^{\mathbf{2}} + \boldsymbol{B}(\dot{\boldsymbol{m}}) + \boldsymbol{C}$; [ΔP] = psi, [$\dot{\boldsymbol{m}}$] = lb/min

Table 31: Curve Fit Parameters for TWHs

Unit	A	B	C	R^2
Non-condensing	0.0054	-0.0115	0.0817	0.9999
Condensing 1	0.0077	-0.0269	0.1445	0.9999
Condensing 2	0.0117	0.0637	-0.0612	0.9981
Condensing with small 2 L buffer tank	0.0173	-0.0454	0.3842	0.9974

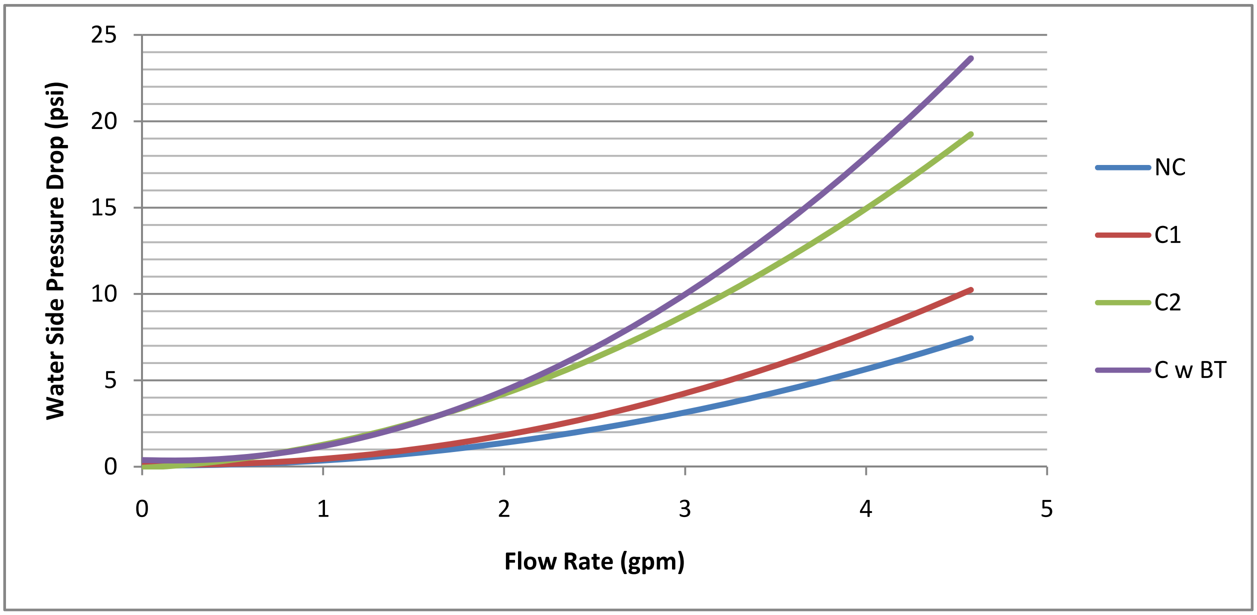


Figure 26: Pressure Drop Curve Fits for TWHs

Short Term Tests

Short term tests are performed on the non-condensing, condensing 1, and condensing 2 TWHs. Short term tests follow the general pattern of hot water draw duration and intermittency as shown in **Error! Reference source not found.**, with the following flow rate and temperature settings used:

Table 32: Short Term Test Matrix – Non-Condensing TWH

	Target Flow Rate (gpm)	Target Temperature (F)	Target Output (Btu/hr)
Test 1	3.0	130	90,000
Test 2	0.7	130	21,000
Test 3	3.0	110	60,000
Test 4	1.5	110	30,000
Test 5	0.7	110	14,000
Test 6	3.0	116	69,000
Test 7	4.0	110	80,000
Test 8	1.5	130	45,000

Table 33: Short Term Test Matrix – Condensing TWHs

	Target Flow Rate (gpm)	Target Temperature (F)	Target Output (Btu/hr)
Test 1	3.0	130	90,000
Test 2	0.7	130	21,000
Test 3	3.0	110	60,000
Test 4	1.5	110	30,000
Test 5	1.5	130	45,000
Test 6	4.0	130	120,000

The following charts track the variation in firing rate, tracked with a mass flow meter, following a cold start.

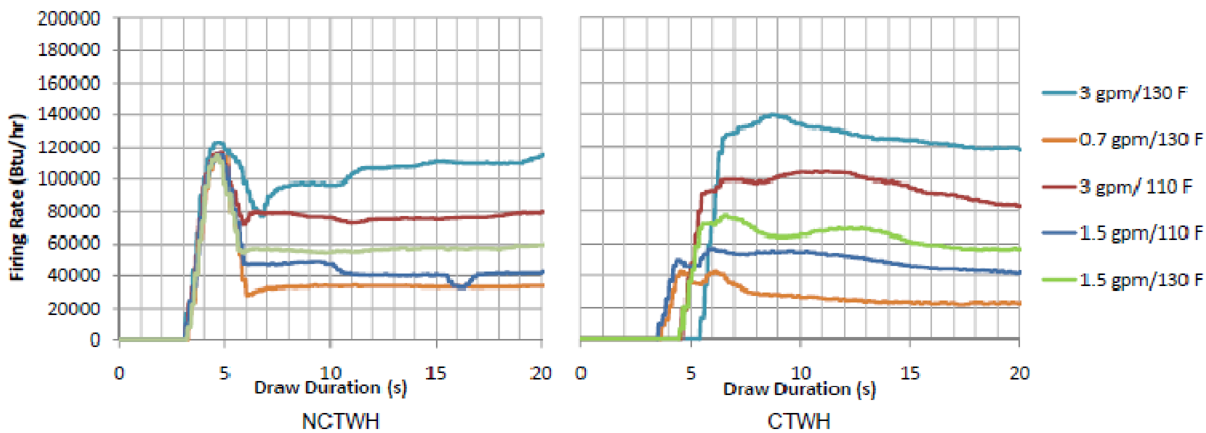


Figure 27: Cold Start Firing Rate vs. Time during Short Term Tests – NCTWH (left) and a CTWH (right)

As in Figure 27 and Figure 28, the Non-Condensing Tankless Water Heater (NCTWH) "assumes" the load is approximately 120,000 Btu/hr, initially fires at this rate, and then adjusts from there, which results in a several second delay for lower firing rates. The Condensing Tankless Water Heater CTWH uses finer control to land near the steady state load initially, with a delay.

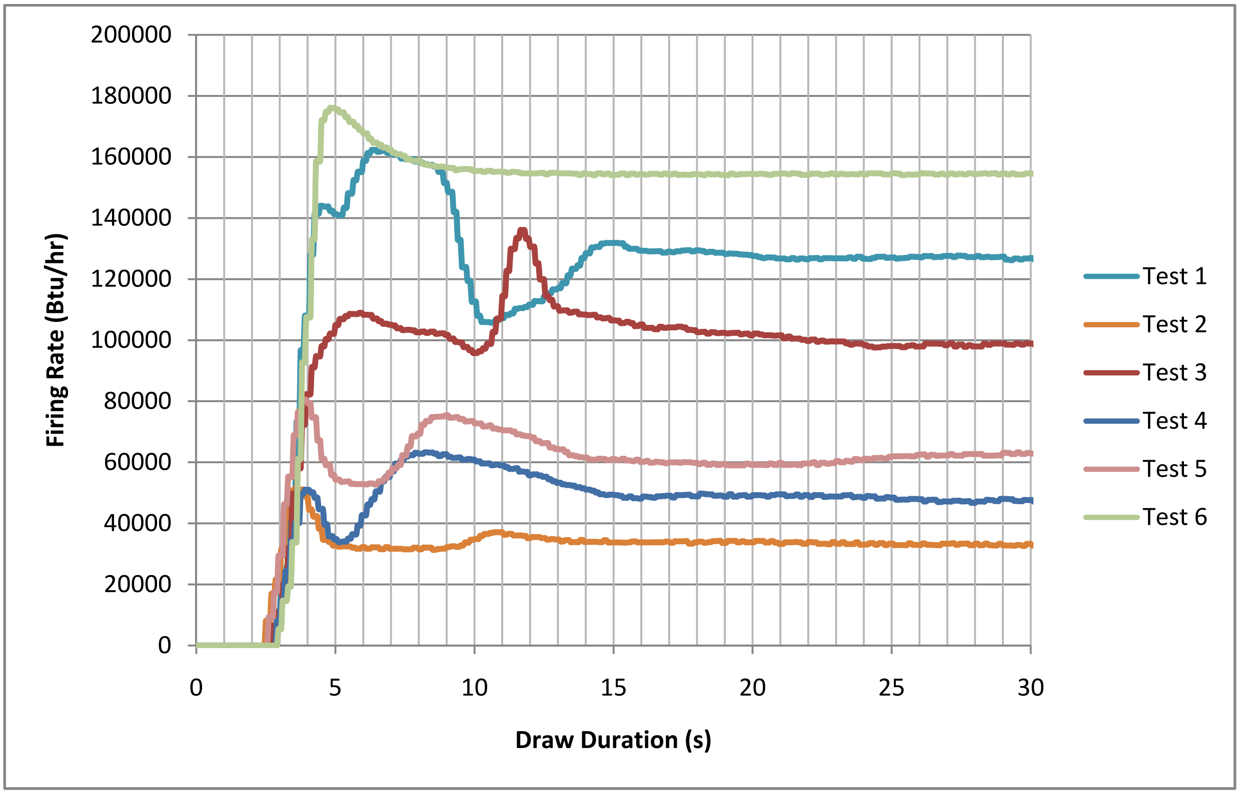


Figure 28: Firing Rate vs. Time during Short Term Tests – Condensing 1 TWH Cold Start

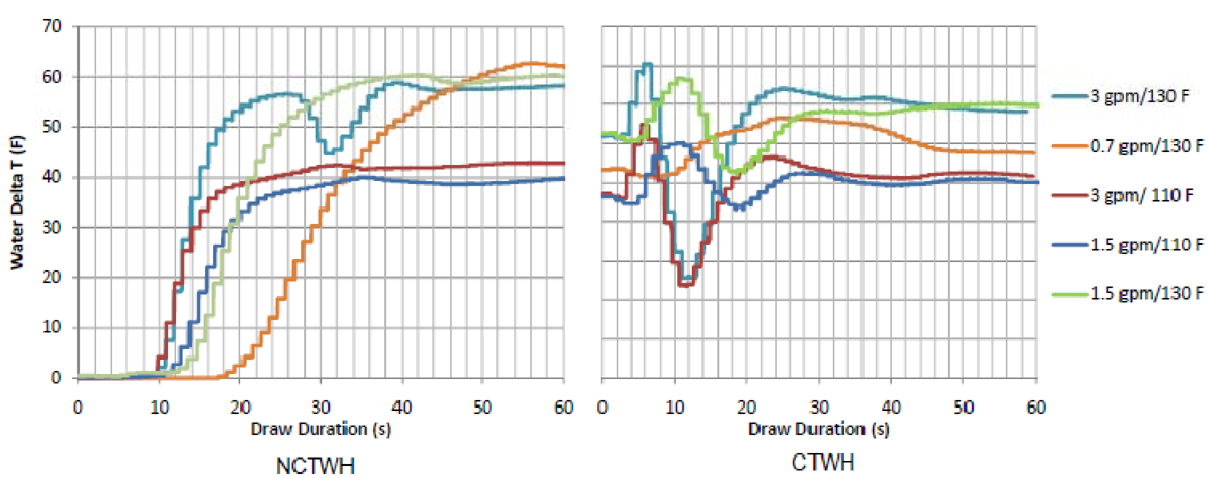


Figure 29: Intermittent Draws Firing Rate vs. Time during Short Term Tests – NCTWH (left) and a CTWH (right)

While this hunting behavior of the firing rate is apparent following a cold start, observing the firing rate following a recent fire, 30 seconds prior, shows a different story in Figure 29. Using an "enhanced" standby mode, not only does the unit fire much closer to the beginning of the water draw, but also the hunt-and-seek behavior is more muted. This behavior is also seen in the Two Shower Test in Figure 30 and Figure 31. At the beginning of the second draw, there is a brief interruption in firing and out temperature drop of 20 F, while with the CTWH there is good temperature control with both events.

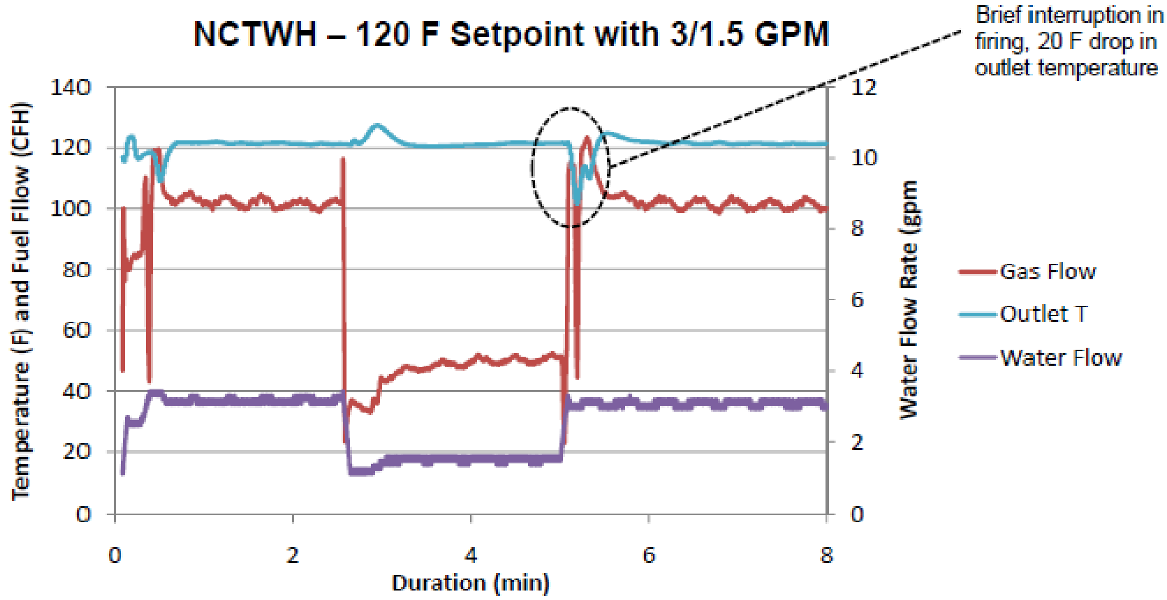


Figure 30: Short Term Test- Two Shower Draw NCTWH

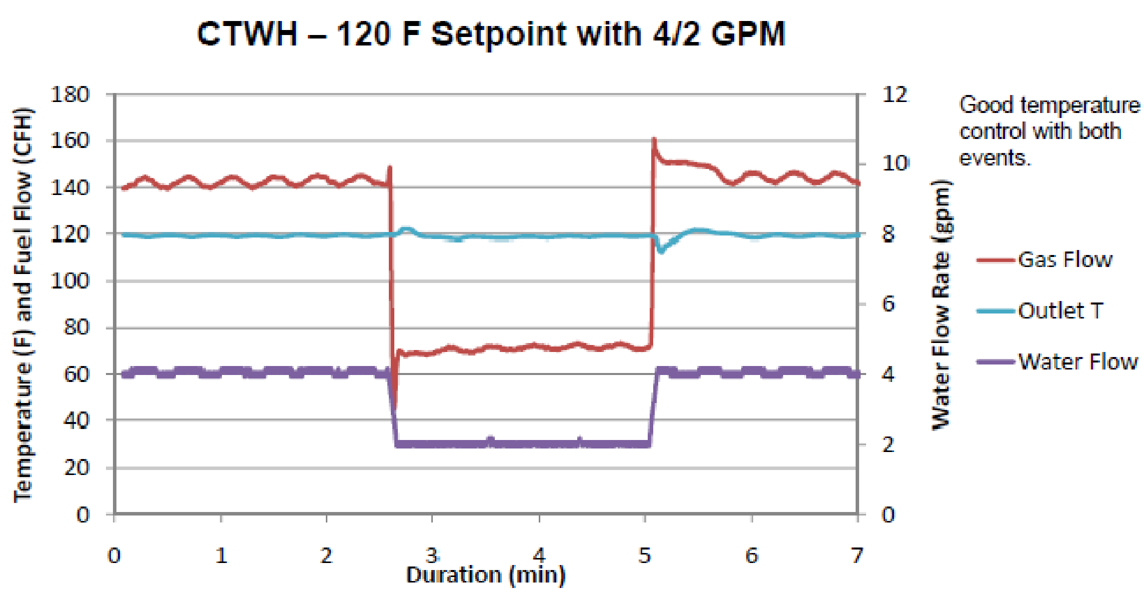


Figure 31: Short Term Test- Two Shower Draw CTWH

Condensing TWHs use finer controls, and in general reach their steady state firing rate directly. Fine tuning is required following the initial firing rate overshoot in some cases for Condensing 1 TWH, however in general the hunt-and-seek behavior observed in the NCTWH, causing delays to deliver hot water at the target temperature, is not found. Observing effects for subsequent draws show very similar behavior, suggesting that an "enhanced" standby mode is not employed. During each of the six draws for each test in the matrix, the delay to fire is recorded and shown in Figure 32 through Figure 34. In examining the non-condensing TWH, the delay to fire is greatly reduced from the initial cold start to the intermediate draws. The delay increases following the fifth draw, suggesting that the unit operates with an "enhanced" standby mode for up to approximately 5 minutes.

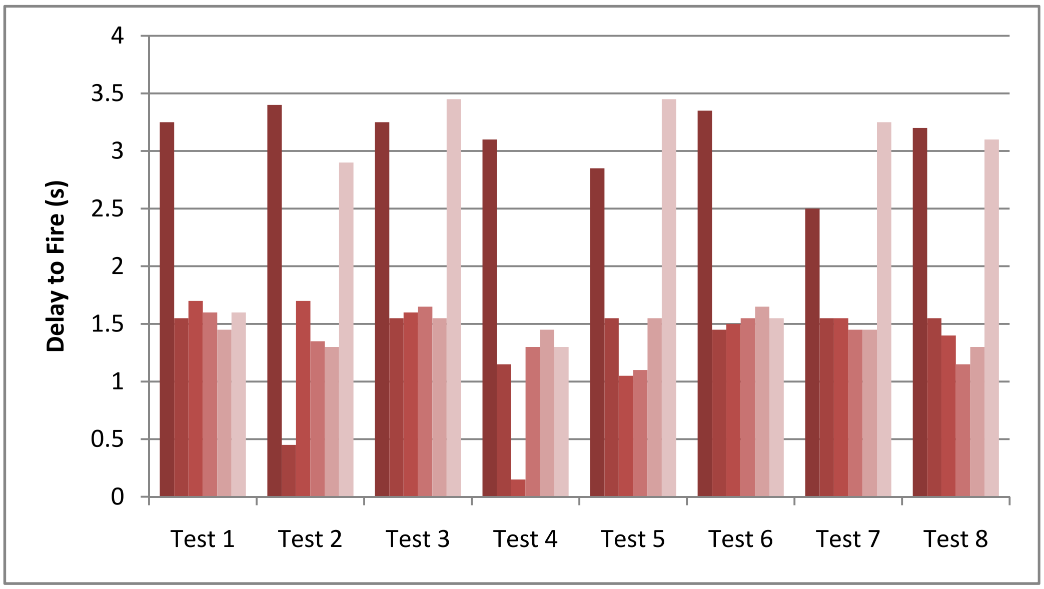


Figure 32: Delay to Fire (s) for Non-Condensing TWH

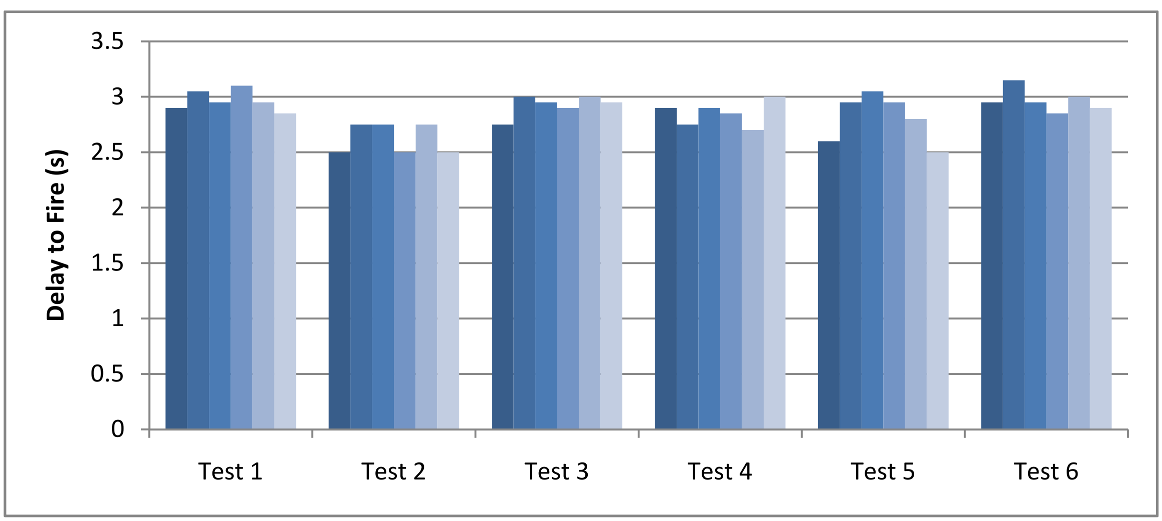


Figure 33: Delay to Fire (s) for Condensing 1 TWH

Figure 34: Delay to Fire (s) for Condensing 2 TWH

Two Shower Tests

For the following tests outlined below, from **Error! Reference source not found.**, the results data are reported in Table 34. Note that the time to reach stable water temperatures is defined as the time from the start of a step change in draw to reach the minimum ΔT as calculated over a 1 minute period (5 second averaging). There does not appear to be a clear trend of condensing vs. non-condensing or condnesing with vs. without an onboard storage volume.

In the case of the Condensing 2 TWH, the manufacturer suggests that a procedure be performed on the TWH following installation to calibrate the unit to the fuel heating value. The calibration procedure requires that the unit be placed in specific diagnostic mode and the maximum water draw rate is applied for several minutes. Following this procedure, the unit will maintain the calibrated power rating while it is powered down and restarted in the standard operating mode. In the field following installation, this calibration will be performed automatically after extended normal operation per manufacturer guidance. As this calibration affects the outlet tempreature control, the Condensing 2 TWH is tested in uncalibrated (out of the box, like the other TWHs) and calibrated modes. Tests with standard inlet temperatures, 1, 2, and 4, will be repeated with the calibrated Condensing 2 TWH.

Test	Set Point (F)	High/Low flows (gpm)	Incoming Water Temperature (F)
1	120	3/1.5	58 - Normal
2	120	4/2	58 - Normal
3	120	4/2	95 - Elevated
4	140	4/2	58 - Normal

Table 34: Time to Reach Stable Water Temperature during Two Shower Tests

			Time to stable water (s)			
			Test 1	Test 2	Test 3	Test 4
Non-condensing		Hi/Lo	14.1	18.5	13.4	33.3
		Lo/Hi	33.7	42.5	26.6	41.2
Condensing 1		Hi/Lo	41.3	26.5	14.7	36.7
		Lo/Hi	21.7	10.0	30.5	24.4
Condensing 2	w/o Calibration	Hi/Lo	15.6	33.5	13.5	32.4
		Lo/Hi	26.4	38.2	39.8	28.7
	w/ Calibration	Hi/Lo	33.7	31.5	n/a	29.7
		Lo/Hi	36.1	21.4	n/a	29.9
Condensing with BT (Inactive)		Hi/Lo	12.4	25.6	20.3	30.1
		Lo/Hi	41.8	15.9	35.0	37.2

Before and after each abrupt transition in outlet draw rate, the variations in flow rate and outlet temperature are analyzed and the maximum departures are recorded for both the High/Low and Low/High transitions. The temperature departures are grouped by (a) the difference between the maximum observed temperature during a transition and the average temperature recorded during the preceding or following high draw, Table 35; and (b) the difference between the minimum observed temperature during a transition and the average temperature recorded during the preceding or following high draw, Table 36. For example, the first cell of Table 35 indicates that under Test 1 conditions at the High-to-Low flow transition, the difference between the maximum temperature recorded during this transition and the average outlet temperature at the initial High Flow is 1.1°F. All temperature departures greater than 5.0°F are in **bold.** The uncalibrated Condensing unit 2 has non-trivial overshoot during high/low transitions and undershoot during low/high transitions, which are with few exceptions minimized by the calibration procedure. Similarly, the non-condensing TWH has significant undershoot during low/high transitions, which in both cases these TWHs briefly interrupt firing during the step change load leading to the observed outlet temperature undershoot.

Table 35: Temperature Overshoot

		Flow Transition	Temperature - [Max T – Avg High T] (°F)			
			Test 1	Test 2	Test 3	Test 4
Non-condensing		Hi/Lo	1.1	3.7	0.6	**5.6**
		Lo/Hi	-0.3	1.1	-0.1	0.5
Condensing 1		Hi/Lo	4.9	3.3	0.1	**6.7**
		Lo/Hi	0.8	0.7	0.8	-0.3
Condensing 2	w/o Calibration	Hi/Lo	**7.7**	**10.6**	**5.1**	**13.7**
		Lo/Hi	0.4	1.1	4.6	0.7
	w/ calibration	Hi/Lo	4.1	**8.6**	n/a	**12.6**
		Lo/Hi	1.0	3.0	n/a	4.1
Condensing with BT (Inactive)		Hi/Lo	0.6	3.1	1.5	**5.5**
		Lo/Hi	-0.8	-0.8	0.4	-0.7

Table 36: Temperature Undershoot

		Flow Transition	Temperature - [Avg High T – Min T] (°F)			
			Test 1	Test 2	Test 3	Test 4
Non-condensing		Hi/Lo	0.4	0.8	0.3	0.4
		Lo/Hi	**20.2**	**30.6**	**5.2**	**32.7**
Condensing 1		Hi/Lo	0.6	-0.5	0.8	0.3
		Lo/Hi	3.6	**5.7**	2.4	**11.6**
Condensing 2	w/o calibration	Hi/Lo	1.4	**12.1**	0.5	**15.3**
		Lo/Hi	**15.8**	**16.7**	**5.4**	**19.6**
	w/ calibration	Hi/Lo	1.1	**5.7**	n/a	**8.3**
		Lo/Hi	**9.2**	**10.3**	n/a	**19.1**
Condensing with BT (Inactive)		Hi/Lo	0.1	-0.3	0	-0.5
		Lo/Hi	2.2	3.9	1.2	**8.8**

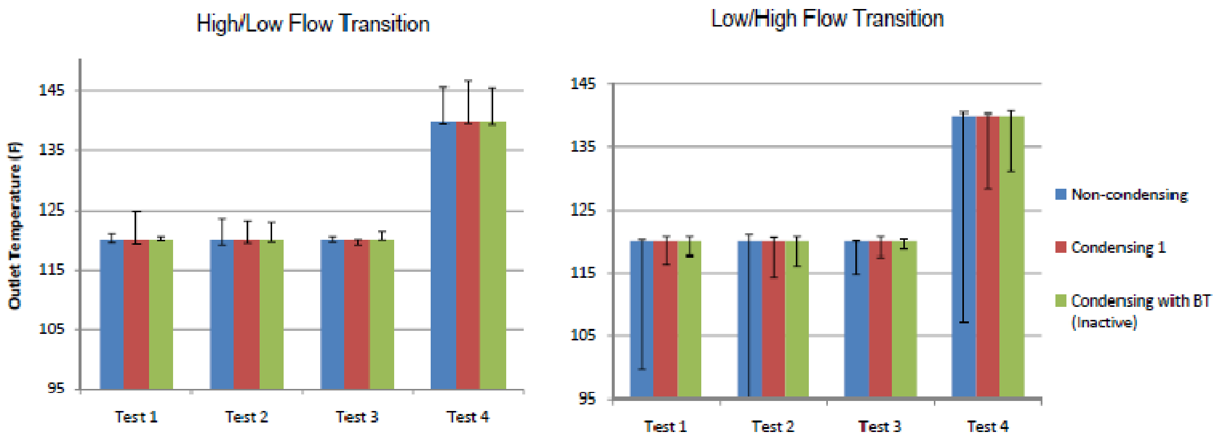


Figure 35: Temperature Overshoot/Undershoot during flow transitions

Similarly, flow variations are analyzed, with variations on the order of 1.0 gpm assumed to be the result of flow restriction and cold water bypass control. In Table 37, the values shown is the difference between the maximum flow rate recorded during a transition and the average flow rate recorded during the preceding or following high draw. In Table 38, the values shown is the difference between the minimum flow rate recorded during a transition and the average flow rate recorded during the preceding or following low draw. During Test 3, with an elevated inlet temperature of 95°F, all TWHs show flow rate spikes during the low/high transition, indicating a delayed use of flow control. Additionally, the non-condensing TWH shows the use of flow control & cold water bypass usage during test 2. In the low/high transition, the flow control of the non-condensing TWH is slower to react than in other cases, leading to a flow spike of almost 2 gpm, contributing to the large temperature drop of 30°F observed.

Table 37: Flow Rate Variation on High Side

			Flow - High Flow Over/Undershoot (gpm)			
			Test 1	Test 2	Test 3	Test 4
Non-condensing		Hi/Lo	0.12	0.12	0.00	0.37
		Lo/Hi	0.24	**1.84**	**0.86**	0.12
Condensing 1		Hi/Lo	0.12	0.00	0.12	0.12
		Lo/Hi	0.12	0.00	**1.10**	0.24
Condensing 2	w/o calibration	Hi/Lo	0.12	0.00	0.12	-0.12
		Lo/Hi	0.24	0.12	**1.59**	0.49
	w/ calibration	Hi/Lo	0.12	0.00	n/a	0.12
		Lo/Hi	0.24	0.12	n/a	0.00
Condensing with BT (Inactive)		Hi/Lo	0.12	0.12	-0.12	0.00
		Lo/Hi	0.12	0.24	**0.98**	0.24

Table 38: Flow Rate Variation on Low Side

			Flow - Low Flow Over/Undershoot (gpm)			
			Test 1	Test 2	Test 3	Test 4
Non-condensing		Hi/Lo	0.37	0.24	0.24	0.12
		Lo/Hi	0.00	0.12	0.00	0.00
Condensing 1		Hi/Lo	0.12	0.12	0.37	0.24
		Lo/Hi	0.12	0.12	0.00	0.12
Condensing 2	w/o calibration	Hi/Lo	0.00	0.00	0.24	0.12
		Lo/Hi	0.00	0.00	0.00	0.00
	w/ calibration	Hi/Lo	0.12	0.12	n/a	0.12
		Lo/Hi	0.00	0.12	n/a	-0.24
Condensing with BT (Inactive)		Hi/Lo	0.00	0.12	0.00	0.12
		Lo/Hi	0.00	0.12	0.12	0.12

24 Hour Simulated Use Tests

The following tables summarize results from DOE Standard EF, GTI-Mid, and GTI-Low testing:

Table 39: Summary of Results from DOE Standard EF Testing

	EF	Estimated EF	Recovery Eff (high)	Recovery Eff (low)	Average Delivered T (F)
Non-condensing	0.77	0.75	82.0%	74.9%	129.6
Condensing 1	0.92	0.92	94.8%	92.3%	127.5

Table 40: Summary of Results from GTI-Mid Testing

	Estimated EF	Average Delivered T (F)	Input		Output
			Gas (Btu)	**Electricity (Wh)**	**DHW (Btu)**
Non-condensing	0.75	125.31	45,121	323	34,609
Condensing 1	0.90	123.70	43,114	279	39,653
Condensing with BT (Active)	0.67	126.40	54,432	889	38,350
Condensing with BT (Inactive)	0.85	119.79	40,266	486	35,457

Table 41: Summary of Results from GTI-Low Testing

	Estimated EF	Average Delivered T (F)	Input		Output
			Gas (Btu)	**Electricity (Wh)**	**DHW (Btu)**
Non-condensing	0.73	129.90	23,599	301	17,958
Condensing 1	0.87	123.77	19,781	245	17,872

Table 42: Summary of Delays from DOE Standard EF Testing

	Average Delay - Low DOE		Average Delay - High DOE	
	To fire (s)	**To reach 0.95*T_{final}**	**To fire (s)**	**To reach 0.95*T_{final}**
Non-condensing	10.0	69.0	6.0	23.0
Condensing 1	7.0	47.0	6.0	14.0

Table 43: Summary of Delays from GTI-Mid Testing

	Average Delay		Max Delay	
	To fire (s)	**To reach 0.95*T_{final}**	**To fire (s)**	**To reach 0.95*T_{final}**
Non-condensing	4.5	15.1	6.0	28.0
Condensing 1	5.4	27.1	6.0	32.0
Condensing with BT (Active)	6.5	13.1	7.0	31.0
Condensing with BT (Inactive)	11.3	13.4	18.0	54.0

Table 44: Summary of Delays from GTI-Low Testing

	Average Delay		Max Delay	
	To fire (s)	**To reach 0.95*T_{final}**	**To fire (s)**	**To reach 0.95*T_{final}**
Non-condensing	6.9	25.8	10.0	45.0
Condensing 1	4.1	18.7	5.0	38.0

The following data summarize the average quantities for the Condensing TWH with a 2 L Buffer Tank during its 50 recirculation cycles, while performing the GTI-Mid draw pattern. The TWH allows for scheduling of the recirculation, the test is performed with 24 hr/day of recirculation.

Table 45: Average Values over 50 Recirculations during GTI-Mid Test for Condensing with Buffer Tank TWH

	Average
Duration (s)	28.5
Electricity Consumed (Wh)	4.9
Gas Consumed (Btu)	232.6
Firing rate (Btu/hr)	29,467
Power Draw (W)	665.4
	Total
Duration (min)	23.8
Power Drawn (Wh)	247.0
Gas Burned (Btus)	11,632

Table 46 TWHs – 24 Hour Simulation Use Tests Operating Costs

		Non-condensing	Condensing 1	Condensing with Buffer Tank (24 hr*)	Condensing with Buffer Tank (Inactive*)
Estimated Annual Operating Cost	DOE Standard EF	$201.74	$157.49	Not tested	
	GTI Mid Draw	$178.11	$168.47	$243.59	$170.29
	GTI Low Draw	$100.72	$84.03	Not tested	
Gas Consumed (therms)	DOE Standard EF	0.500	0.394		
	GTI Mid Draw	0.451	0.431	0.544	0.403
	GTI Low Draw	0.236	0.198	Not tested	
Electricity Consumed (Whs)	DOE Standard EF	433.9	313.6		
	GTI Mid Draw	322.9	278.8	889.3	485.5
	GTI Low Draw	300.5	245.0	Not tested	

2010 Mid CA Electricity Price	0.1575	$/kWh
2010 Average CA Natural Gas Price	0.9688	$/therm

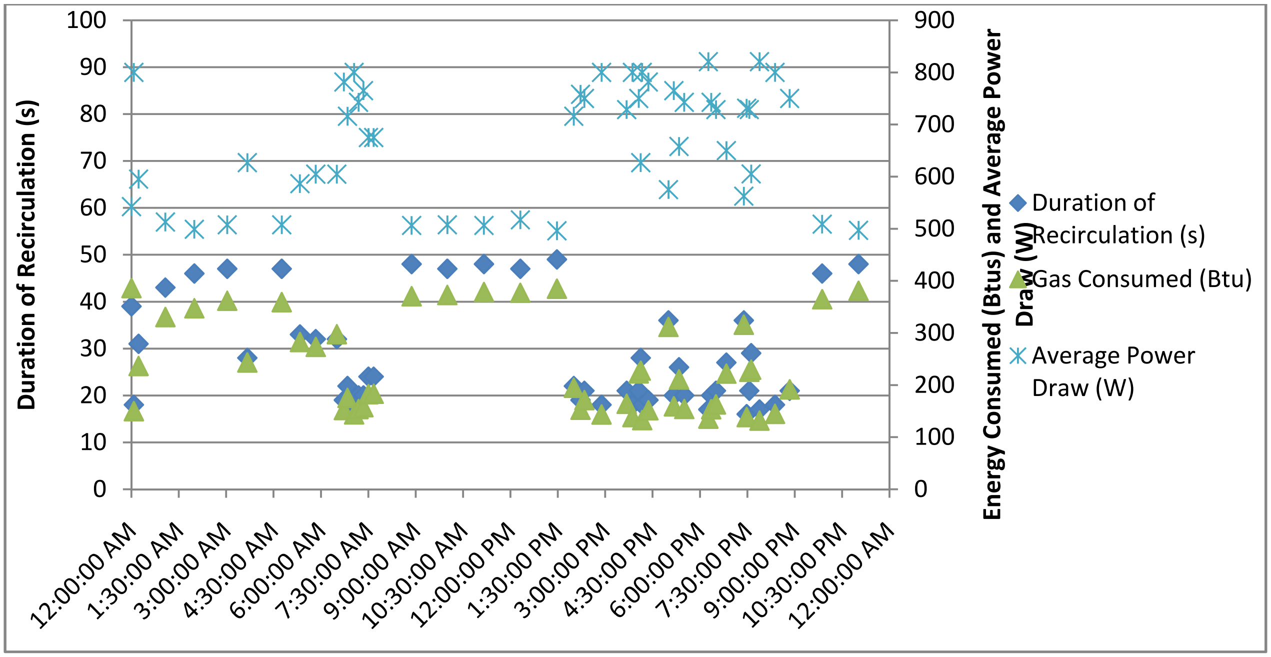


Figure 36: Breakdown of Condensing w/ Buffer Tank Recirculation Behavior (24 hour recirculation schedule)

Appendix K: Baseline and Advanced Water Heater Field Tests Field Monitoring Plan

BACKGROUND & OBJECTIVES

This monitoring plan outlines the equipment and the methodology to be used in monitoring the performance of eighteen residential hot water installations under the Gas Technology Institute's Residential Water Heating Program. The goal of the monitoring is to document the performance of the existing gas hot water heaters in the homes, and then monitor the performance of replacement advanced gas water heater systems in the same homes. Six homes each will be monitored in PG&E, SCG, and SDG&E service territories, with each of the six homes to have a different advanced high-efficiency gas water heater system installed.

Key steps in the field monitoring effort include:

1. Select monitoring sites.
2. Install and commission monitoring equipment that will characterize water heater gas and electricity consumption, hot water consumption, energy delivered to the hot water distribution system, and water heater inlet, outlet, and environment temperatures.
3. Collect four months of base case data (existing water heater) and survey homeowners on hot water use behavioral aspects.
4. Coordinate replacement of each existing water heater with one of the six advanced gas water heater types.
5. Re-commission monitoring systems and monitor advanced water heaters for a minimum of four months. Homeowners would again be surveyed on their overall perception of the advanced water heater and how they felt it affected their overall consumption or patterns of hot water use. The monitoring data can then be reviewed to see if the survey responses support the data.
6. Evaluate data and complete a monitoring report covering monitoring methodology, results, and conclusions.

STRATEGY AND METHODS

General Approach

The primary aim of this monitoring project is to collect data that will describe the in-situ operating efficiency of conventional storage gas water heaters (representing existing water heater stock in California) and advanced residential water heater technologies that have high nameplate efficiencies, but have not yet been widely tested in the field.

The testing will help provide an initial assessment of these systems's relative efficiency versus both the existing gas storage units found in current housing stock, as well as to the advanced unit's nameplate rating. This information will be helpful in developing a preliminary assessment of economic viability, as well as identifying system performance characteristics that are most significantly affected by operating patterns identified in the field. By monitoring the energy flows into the system (gas and electric consumption), and the energy output to the distribution system, an overall site efficiency can be calculated. Performance differences between the three sites (for each advanced water heater) will provide a preliminary indication of how significantly usage profiles and other parameters affect system performance for each of the six advanced water heaters.

Test Sites

Our goal is to select eighteen sites from a pool of potential candidates. The original site selection procedure may include employees from the three utilities. Ideally we would like to have a range of house vintages, house sizes, and family demographics. At this stage in the planning process, we are anticipating that all 18 sites will be single family homes served by a single gas storage water heater dedicated to water heating. To provide some level of consistency in performance comparisons across the three utilities, we will exclude houses that have solar (or other auxiliary) pre-heating, recirculation systems, or combined hydronic systems. We hope to complete the site selection process by the end of March, allowing for equipment installation in April or May. A sample site data sheet is included in Figure 37.

Table 47: Monitoring Point Description

Monitoring Point	Sensor Description	Used For
Cold water inlet temperature	Immersion temperature sensor in cold water line to water heater	Calculating hot water delivery energy (Btu's)
Hot water outlet temperature	Immersion temperature sensor in hot water line from water heater	Calculating hot water delivery energy and delivery temperature stability
Domestic hot water flow rate	In-line turbine flow meter on cold water line to water heater	Calculating hot water delivery energy (Btu's) and when a draw occurs
Water heater environment temperature	Air temperature sensor located in area near water heater	Determining standby loss as a function of temperature
Water heater gas use	Gas meter with pulser on gas line to water heater	Gas energy consumed
Water heater electrical usage	True RMS power transducer on electrical supply to water heater	System parasitic energy use

Key Monitoring Parameters

Key field data recorded for evaluating and comparing water heating system performance, and methods for obtaining the data are listed in Table 47.

Data Acquisition Approach

The sites will be equipped with a Data Electronics DT50 datalogger and modem for collecting, storing, and transferring data via a dedicated telephone line. A monitoring point list and hardware specifications are provided in Table 48.

The flow meter will be scanned continuously at five second intervals to detect hot water draws. Once flow from a hot water draw is detected, the datalogger will initiate "event based" logging which will characterize each hot water draw event with a unique logged record with the following data collected:

1. Cold water inlet temperature
    a. Average
    b. End of draw
2. Hot water outlet temperature
    a. Average
    b. Maximum during draw
    c. Standard deviation for the period beginning one minute after draw ensues until the end of the draw.[8]
3. Hot water draw volume
    a. Total
    b. Volume at a temperature > 105°F (assumed minimum use temperature)
    c. Flow rate standard deviation
4. Time

---

[8] The one minute delay is designed to insure that tankless water heaters have reached steady state. The standard deviation will provide an indication of how well the water heater can maintain a fixed steady state hot water temperature during longer draws.

    a. Start of draw
    b. Duration
5. Thermal energy delivered during the draw
6. Gas consumption during the draw

In addition to the event-based logging, additional logging will occur on fixed 15 minute intervals. This fixed interval logging will include:

1. Average water heater environment temperature
2. Gas and electrical energy consumption
3. Number of hot water draws
4. Total hot water flow volume
5. Burner firing fraction
6. Number of burner starts

Datalogger memory is sufficient to store more than a week of data, so that loss of communications will not interrupt the stream of data. The datalogger is powered by a low voltage power supply with battery backup to protect against data loss during power outages. Data storage cards will be installed at sites more than 100 miles from Davis Energy Group's office to provide added backup.

Data, in comma-delimited ASCII format, will be downloaded nightly to a central computer and screened using software to insure that the data falls within acceptable ranges. Out-of-range data will be reported and investigated to determine whether a sensor or monitoring error exists or equipment has failed.

Monitoring Period

The current plan is to monitor all eighteen homes for a minimum of eight months: four months in base case mode, and four months in advanced water heater mode. If the project budget allows for additional monitoring, the length of the advanced water heater period may be extended. Preliminary planning involves beginning the base case monitoring in the 2nd quarter of 2010, resulting in base case data collection extending from spring to mid-summer. The advanced water heater testing will likely begin in mid- to late summer.

MONITORING SYSTEM DESIGN

Datalogger Specifications

Data Electronics dataloggers will be used to collect and store monitoring data. DEG has used these loggers extensively over the past 20 years. Although newer Data Electronics models have entered the marketplace, the DT50 has proven to be a accurate and reliable logger over the years. In addition, the new DT81 or DT82 models require a slightly different programming language.

Sensor Types and Specifications

Table 48 lists the types of sensors that will be used for the various monitoring points and their performance specifications. Sensor selection will be based on functionality, accuracy, cost, reliability, and durability. Specific model numbers are listed as examples. Signal ranges for temperature sensors correspond approximately to listed spans.

Table 48: Sensor Specifications

Application	Type	Mfg/Model	Signal	Accuracy
Air temperature	Type T thermocouple	-	Millivolt	±0.5°C
Water temperature	Type T thermocouple	Gordon 20CTOUH	Millivolt	±0.5°C
Electric use	Power transducer	CCS WNB-3Y-208-P	1.3 pulses/wh	±0.5%
Gas use	Gas meter	American AC-250	10 pulses/cuft	±1.0%
Water flow	Turbine flow meter	Onicon F1300	500 pulse/gal	±2.0%

Equipment Panel

The datalogger, modem, battery backup, and power supplies will be mounted in a locking NEMA-1 cabinet. See Appendix 2 for typical datalogger wiring layouts.

MONITORING SYSTEM INSTALLATION

Datalogger Installation

The datalogger panel will be installed in close proximity to the water heater, most likely in the garage, or interior or exterior closet. Communications will be established via either land-line or cellular telephone service. The panel cover will be marked with a contact and phone number for the homeowner to call in the event of problems.

Sensor Installation

The following procedures will be followed during the installation of the various sensor types:

Flow meters. The in-line flow meter will be installed in the cold water supply line to the water heater with a minimum 5 pipe diameters of straight pipe downstream and 20 diameters of straight pipe upstream of the flow meter.

Immersion Thermocouples. Immersion thermocouples will be installed on the cold water inlet and the hot water outlet, a minimum of two feet from the water heater. The thermocouple probe will be positioned in the center of the pipe.

Environment Temperature. A thermocouple will be located in the general area of the water heater. The height of the sensor will be between 4-5 feet, and the sensor will be shielded to minimize radiative gains from water heater piping and/or other sources.

Gas meter. A pulsing gas meter (minimum 10 pulses/cuft) will be installed on the gas line feeding the water heater.

Power monitor. A true RMS power transducer will be installed on the mains supply to the advanced water heater, if the unit consumes electricity.

DATA REVIEW AND DATA ANALYSIS

Data will be downloaded on a nightly basis to DEG's central computer and will be logged in .csv format in monthly data files for each site. An Excel spreadsheet will be developed that can input a weeks worth of data and compute totals, averages, max/min values, as well as provide a graphical time series of key temperatures, energy flows, and energy use. This spreadsheet will be used to screen data on a bi-weekly basis to verify that all sensors are working properly and that the water heater is operating correctly. (Observed anomalies will result in further investigation and possibly a service call, if warranted.) Regular review of the graphical output will also facilitate the identification of unusual water heating events such as peak load conditions, or operating patterns which cause the system to not maintain specified outlet temperatures.

Operating Efficiency

Both base case and advanced water heater operating efficiency can be calculated using the following equation.

Equation 44: Water Heating Efficiency

$$\acute{\varepsilon}\ (\text{Operating Efficiency}) = Q_{Output} / Q_{Input}$$

Where:

Q_{Output} (Btu) = Draw Volume (gal) x 8.33 lbs/gal x 1.0 Btu/lb-°F x ($T_{Hot} - T_{Cold}$)

Q_{Input} (Btu) = Gas Use (Btu) + Electric Use (Wh) * 3.413 Btu/Wh

(site energy calculation)

$\mathbf{Q}_{\mathbf{Output}}$ will be calculated and logged for each individual draw, while $\mathbf{Q}_{\mathbf{Input}}$ will be calculated from the 15-minute interval data. The operating efficiency calculation will have increasing significance over longer time scales, especially for water heaters with storage where standby loss can overwhelm useful heat delivered on days with very low hot water draw volumes. For this study, we will calculate $\acute{\varepsilon}$ on a daily and monthly basis. Operating efficiency is expected to vary with usage patterns and also to some degree with seasonal effects, such as environment temperature and cold water inlet temperature.

GTI Residential Water Heating Program Date: ____________

Advanced Water Heater Field Testing Site Survey Site #: ____________

Site

Address: ____________________ House vintage (~year): ____________________

City: ____________________ Floor area (sqft): ____________________

# of bedrooms: ____________________ # of full bathrooms: ____________________

Notes: ____

Occupants

	Adults	Children (3-18)	Infants (<3 years)
Year round:			
Part year:			

Notes: ____

Water Heater

Size (gallons): ____________________ Location: ____________________

Manufacturer: ____________________ Model #: ____________________

Input (kBtu): ____________________ Age: ____________________

Vent (type, location): ____________________ Distance to 120V (ft): ____________________

Gas line size: ____________________ Distance to meter (ft): ____________________

☐ Pipes insulated ☐ Heat traps ☐ Tank wrap

Combustion issues: ____

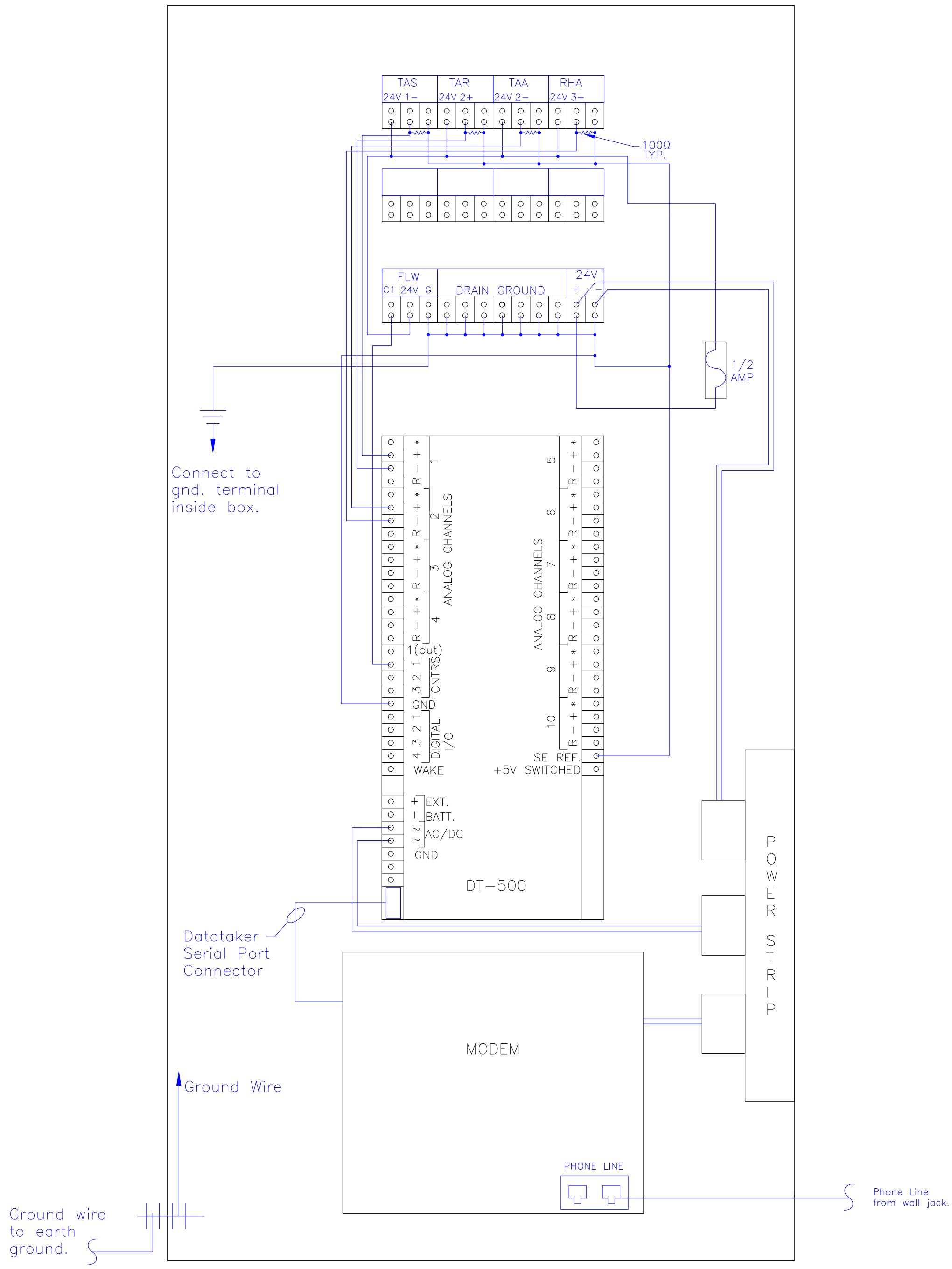
Notes: ____

Fixtures

	(List use points) Name	Manufacturer (CW/DW) & Model #	Wait time (mm:ss)[1] Model (CW/DW)	Aerator	Single lever
1.	Clothes washer			☐	☐
2.	Dishwasher			☐	☐
3.				☐	☐
4.				☐	☐
5.				☐	☐
6.				☐	☐
7.				☐	☐
8.				☐	☐
9.				☐	☐
10.				☐	☐
11.				☐	☐
12.				☐	☐
13.				☐	☐
14.				☐	☐
15.				☐	☐
16.				☐	☐

[1] Measure wait time at most remote bathroom or kitchen fixture. Measure wait time for sink or shower (not tub).

Figure 37: Sample Site Data Collection Form



DAVIS ENERGY GROUP, INC.
123 C Street, Davis, CA 95616
(916) 753-1100

Building America Hot Water Study
SITES S1 – Lot 302
PANEL WIRING DIAGRAM

SCALE: NONE
DATE: 08/12/03
DRAWN BY: SB JOB: BLDAM–T02
SHEET 1 OF 1 SHEETS

Figure 38: Example Monitoring Panel Layout

Appendix L: Baseline and Advanced Water Heater Field Tests Advanced Water Heater Specifications

Site ID	Manufacturer Make & Model Installed	Product Spec Sheet Hot Link
SD1	Noritz NR-71-SV	http://www.noritz.com/professionals/products/view/nr71_n_0631s_series_residential_tankless_water_heater/
SD2	AO Smith GPHE-50	http://www.hotwater.com/lit/spec/res_gas/AOSRG45100.pdf
SD3	Navien NR-240A	http://www.navienamerica.com/PDS/ftp/NavienCondensingTankless/NR_NP/Brochure/Navien_condensing98_091208.pdf
SD4	Rinnai RC80HPi (KA2530FFUD)	http://www.rinnai.us/documentation/downloads/RC80HPi_SP.pdf
SD5	Bradford White D-4-504S6FBN	http://www.bradfordwhite.com/images/shared/pdfs/specsheets/120-B.pdf
SD6	AO Smith GAHH-40	http://www.hotwater.com/lit/spec/res_gas/AOSRG46900.pdf
LA1	Noritz NRC111-DV (N-0842MC-DV)	http://www.noritz.com/u/842_info_sheet.pdf
LA2	Rheem 42VP40FN	http://globalimageserver.com/fetchDocument.aspx?id=b3698a2c-4a47-42e2-b826-e6da9ba4109e
LA3	Bradford White U-4-TW-60T6FRN	http://www.bradfordwhite.com/images/shared/pdfs/specsheets/259-B.pdf
LA4	Rheem (Paloma) RTG-84DV	http://globalimageserver.com/fetchDocument.aspx?id=e5e75c4c-f096-4b14-a182-ad8b759ec421
LA5	Nortiz NR66-SV	http://www.noritz.com/professionals/products/view/nr66_n_0531s_series_residential_tankless_water_heater/
LA6	NA	NA
PG1	Navien NP-240	http://www.navienamerica.com/PDS/ftp/NavienCondensingTankless/NR_NP/Brochure/Navien_condensing98_091208.pdf
PG2	Bradford White EFR-1-60T1206EN	http://www.bradfordwhite.com/images/shared/pdfs/specsheets/123-B.pdf
PG3	AO Smith GPVR-40	http://www.hotwater.com/lit/spec/res_gas/AOSRG45600.pdf
PG4	Rheem PDV40	http://globalimageserver.com/fetchDocument.aspx?id=d5d877f4-3a5b-4e36-a757-ccfde987552e
PG5	Rinnai RC98HPe (KA3237WD-US)	http://www.rinnai.us/documentation/downloads/RC98HPe_SP.pdf
PG6	AO Smith HYB-90N	http://www.hotwater.com/lit/spec/res_gas/AOSYG45000.pdf

Appendix M: Baseline and Advanced Water Heater Field Tests Homeowner Survey Responses

Homeowner Post-Installation Survey (Completed ~ 3 months after equipment install)

1. *With some households we are aware that there has been a change in the number of people living there. Can you please describe to the best of your ability, the approximate dates of these changes, and how long they lasted?*

LA1	There were no changes from the original plan, but every other week (on Monday Nights, Tuesdays and Wednesdays) we had a 2 year old baby and a 70 yr old senior.
LA2	Hosted a college student for the month of June 2010 My sister in law moved in approximately February 7, 2011
LA3	None
LA4	None
LA5	We had my daughter, her husband and their child move out on April 9, 2011.
LA6	
PGE1	None
PGE2	None
PGE3	None
PGE4	Only 1 at home 7/8/10-7/24; 9/3-9/7; 12/17-12/21; 3/16-3/20; 3/31-4/10 (33 days in all).
PGE5	Daughter moved out first week of January 2011.
PGE6	Housesitter last week of March 2011
SD1	None
SD2	Two adults added to household first week of January 2011
SD3	Some weekend stays from out-of-town son.
SD4	None
SD5	Nothing significant.
SD6	None

2. *Any performance issues with your new water heater? (e.g. varying temperatures during shower, ability to handle multiple draws, etc.)*

LA1 Yes, the water constantly alternated between cold and hot and it took a very long time (almost a minute) to get hot in the upper floor bathrooms. We noticed than when two people tried to take simultaneous showers, one got mostly cold water.

LA2 Water seems to get warmer during a shower so that about ½ way through the shower, I have to turn down temperature.

LA3 The performance of the WH has been superior to our former heater. The tank is larger, and makes the water hotter than old system.

LA4 No change.

LA5 We haven’t noticed any big changes or performance issues to speak of. At first the time it took for hot water to get to the faucet was a

little frustrating and the fact that the water wasn’t as hot as old water heater but we’ve become accustom to it and it’s working well.

PGE1 None so far, better than expected.

PGE2 No performance issues on the new water heater. In fact we’ve gain performance increases since the installation

PGE3 Everything seemed to be about the same as before the new heater was installed.

PGE4 So far no complaints or issues. It may be my imagination, but the temperature seems higher and it seems to arrive sooner.

PGE5 Zero issues.

PGE6 No – it’s been great!

SD1 Once we dialed in the max temp we have had no issues. The WH has had no problem filling a Jacuzzi bathtub at the end of a long run.

SD2 No performance issues, water heater works great.

SD3 Water becomes hotter, to a point, as the shower progresses. The temperature needs to be adjusted downward when that happens.

SD4 There were a few instances of varying temperature, mostly while doing dishes, but occasionally during showers.

SD5 None.

SD6 No performance issue with the new water heater.

3. *After living with your new water heater over the past several months, what performance attributes do you like (relative to old WH) and not like?*

LA1 Likes

- The potential of never running out of hot water, which never fully materialized.
- Very little gas savings.

Dislikes

- Cold water every time we took simultaneous showers.
- Longer delay to start getting hot water.
- Size of equipment and noise level when the unit kicked-in.
- "Look-and-feel" of installation.
- Overall, bad shower experience.

LA2 Likes

- The flashing blue light on the control

Dislikes

- Humming noise from the WH when heating. The sounds only penetrates into the adjacent bathroom.

LA3 Likes

- Our gas bill seems to be lower, although we haven't had it long enough to be certain.

Dislikes

- Additional exhaust piping from the WH takes up storage space in the garage. Exhaust fan can be heard in the room over the pipe.

LA4 Likes

- Once the water is at the right temp, unless another person draws a lot of water from another faucet, it is just like the old tank unit.

Dislikes

- Additional time to get hot water wastes a lot of water. Considering recirc. Don't like getting cold water blast if someone turns on HW

LA5 Likes

- Money and space savings.

Dislikes

- Having to purchase filters for water treatment.

PGE1 Likes

- Endless hot water when needed, even with maximum simultaneous draws. Uses no energy when the water heater is off.
- Water heater location under the kitchen means I can hear it both firing & modulating, reminding me to turn the hot water flow down
- (or off) when not needed. All parts CAN be repaired/replaced but also more likely to need repair-tradeoff

Dislikes

- Potential maintenance & future repair costs/labor/downtime. Eventual high replacement cost although I left original hookups & flue to
- allow a tank to go back in if desired. Hoping maintenance will extend the life of this unit far beyond tank WH life, even indefinitely.

PGE2 Likes

- Hot water is pushed to the farthest shower much faster from cold to hot.
- Water heater contains more hot water than the existing heater, resulting in more warm water usage throughout the house.
- Water heatup time is cut drastically and hot water is replenished considerably faster.

Dislikes

- The additional necessary intake/exhaust pipes attachment
- Loud whistling sound that the water heater makes when intaking air (can be a defect). Seems like there is an air leak at the air intake.

PGE3 Likes

- Everything seems to be the same on the performance side. Ability to provide sufficient amounts of heated water is a plus.

Dislikes

- The only drawback to the new WH is the noise, since WH is louder than the previous one. I'm assuming it might annoy the neighbors

PGE4 Likes

- No changes in habits required with the new heater. The change has been almost unnoticeable.
- Form factor is about the same as the old unit.
- Recovery time seems faster and there have been no shortages of hot water.

Dislikes

- Can hear fan noise through wall when operating (if I listen for it).
- New PVC vent pipe through roof is unattractive.
- Concerned about electric power consumption and "vampire" load while idle (compared against cost to run pilot light).

PGE5 Likes

- bottomless hot water, wait no longer than old unit (… also a tankless unit….).

Dislikes

- cannot trickle flow, same behavior as previous tankless

PGE6 Likes

- Don't have to wait so long for hot water
- Multiple people can shower one after the other without performance issues

Dislikes None

SD1 Likes

- We like the wall mount & small space that it takes. Although several water purification filters installed, there is still room for small storage cabinet after the monitoring equipment is removed. Complex installation that looks good and receives many comments.
- We like the fact that we are saving a significant amount of natural gas (hopefully) and not keeping water hot when we are not using it.
- There has never been a shortage of hot water; however, we do not intend to change our hot water usage to test it.
- We like the ease of periodic maintenance of the hot water heater and replacement filters and intend to keep up on this.

Dislikes

- The primary dislike of the tankless water heating system is the additional time and water usage that it takes to have hot water in the

- bathrooms at the end of a long run. In addition, if we use hot water intermittently when washing dishes or taking a shower, we notice
- that the water temperature tends to change from hot to warm due to the cycling of the tankless heater as compared to a tank storage.

SD2 Likes

- The water temp is constant which is very nice. The old one delivered water at varying temps, sometimes too hot, sometimes too cold.

Dislikes

- The water heater is bigger than the previous one and because of its height, needed to be installed slightly away from the existing stand in our garage. So a little bit of extra space is used up. Not a big deal.

SD3 Likes

- Unlimited hot water and less gas consumption

Dislikes

- Even after adjusting the (..tankless unit buffer tank..) recirculating option, a bit more water is being used (& caught in a bucket)
- in the warm-up period waiting for hot water to reach the upstairs shower & upstairs bathtub.

SD4 Likes

- I am hoping that it is saving some energy compared to my old unit, but haven't looked close enough to know. Hopefully evaluation will shed light on this. Never had issues with running out of hot water, but imagine that if I had, this unit would mitigate that.

Dislikes

- Inconsistent water temperature, longer draw time, increased maintenance, decrease in water pressure.

SD5 Likes

- We seem to get hot water faster to the spigot.

Dislikes

- None

SD6 Likes

- Gas bill has gone done but it could be a product of us using the heater less and the weather warms up.
- Aesthetically it looks much nicer than the previous heater.
- Water temperature is more consistent.
- Hot water flow is quicker.
- Digital panel to control the temperature is nice.

Dislikes

- A little concern that the fan might break in a few years as it seems to be running often.

4. *With some of the monitored houses we have seen a change in hot water usage and the number of daily hot water draws. Some of this may be due to occupancy changes. Outside of that effect, if you feel your behavior has changed in response to your new water heater, please describe behavioral changes and what types of hot water draws are most affected?*

LA1 None other than what I explained in item #1

LA2 Increase in the length and number of showers taken by one person – Health reason. Started approximately February 7, 2011. We may have had increase in laundry & dishwashing because of the occupancy change. I think that the WH can keep up with our low flow shower so that we never run out of water when taking a shower. At least no one in the household has noticed. This may cause us to take longer showers.

LA3 No changes that we are aware of.

LA4 I don't perceive that we have made any changes.

LA5

PGE1 Due to the feedback this unit gives me I feel like I run the water at a lower level when handwashing dishes. Otherwise no change. We never really ran out of hot water with the old tank heater, once or twice in 2 years.

PGE2 I believe there are no changes to hot water draws. If anything, it'll be an increase since hot water is more available through the new water heater.

PGE3 I don't think we've really changed our habits too much.

PGE4 No behavior changes have been made or considered necessary.

PGE5 None, other than 3rd occupant moving out first week of January 2011

PGE6 I can't think of anything that would be a persistent change.

SD1 I suspect that any difference in hot water usage is more of a factor of the seasons instead of the device. I probably tend to wash dishes faster and use hot water differently due to the repeated cycling of the tankless water heater and the variability in temperature for short water draws.

SD2 No behavioral change.

SD3 My wife served on a three-week jury (March 29-April 12) and was not home most weekdays during that period, as she normally is.

SD4 My only comment would be potentially increased duration and usage, due to lower (and sometimes inconsistent) temperatures.

SD5 My wife lost her job in December 2010. As a result, she is now home during the day which she wasn't when the survey first started.

SD6 I believe on average I am taking longer showers (2-3 minutes longer). This is partly due to the good hot water temperature and partly because we're no longer dealing with water drought so I am a bit more relaxed in my water conservation efforts. In addition, my wife has started to do Epsom salt bath soaks in the last couple of months.

5. *For those of you with tankless water heaters, we are interested in following up with you again to assess any behavioral changes you may have implemented as you have become more familiar with your unit. Please answer the following questions:*

   a) How has the minimum flow rate performance of your water heater affected how you use hot water?

LA1 Not consciously.

LA4 With a minimum flow rate, I will just use cold water. My wife will let it run until it is hot but usually will turn the hot water

on high and walk away for a while.

LA5 No change for us.

PGE1 Unnoticeable at lowest flows, but I wonder if that will change as the unit ages & perhaps internal flowmeter becomes less sensitive.

PGE5 Familiar with that behavior. We adapted with the first tankless. Sandwich is only a small drop in temp usually, very minor actually,

and lasts for only a handful of seconds. Having to keep the flow above the minimum rate to trigger the burner is somewhat

annoying but have found that there is usually enough hot water in the pipe to meet the trickle use.

SD1 This is probably most evident when washing hands in the bathroom sinks and dishes in the kitchen. We typically do not wait for

hot water when washing hands as the small amount of water used is not worth the extra water wasted. When washing dishes, it can

be somewhat of a problem because the frequent short water draws cause the tankless heater to cycle on and off and we may not get

hot water every time. The behavioral change is that instead of rinsing each item separately, I wait until I have several items to rinse

and rinse them in one water draw.

SD3 It has not affected us

SD4 I haven't noticed a time when this has been an issue. I usually only use hot water in higher flow applications such as showers

or washing dishes. Typically I wash my hands with cold water, or complete the process before the cold water in the pipes has cleared,

so functionally it makes no difference.

b) *Do you feel that the minimum flow rate issue is an inconvenience or actually makes you think more about when you need hot water?*

LA1 Yes, especially when you are in a hurry (very annoying)

LA4 Not really a problem.

LA5 No issue for us.

PGE1 No

PGE5 Min flow is only a problem after you have hot water, throttle back the volume then run out of hot water, like when scrubbing something in the kitchen sink

SD1 At worst, it is a minor inconvenience and it does make us think about our use of hot water. I feel that it helps us be more efficient in our water use and should help out with water conservation.

SD3 Since I recirculate the water in the tank twice a day (…tankess with buffer tank…) , I consider when I use hot water.

SD4 No.

c) *Do you feel that any of your usage patterns have been affected by the unit? Sink draws, showers, others?*

LA1 Yes, all the time; this seems to be a recurring problem, where we never got constant temperature at all.

LA4 My perception is that since we wait longer for hot water, we are more likely to do something else while waiting. That results in even

more water waste. First, more cold water goes down the drain waiting for the hot water. Second, the hot water runs while we are

distracted by another task. With the old WH, the hot water arrived fast enough so we weren't tempted to do something while waiting.

LA5 It takes a little longer for someone to get into the shower, but once in there is no difference.

PGE1 No

PGE5 No. Again because we already learned new and more water and energy efficient habits with the previous tankless. Except our

daughter, who never got out of the shower.

SD1 Yes, as discussed above, I believe that are more likely to group water draws together than before. This is somewhat true

with showers and certainly is true with hot water at sinks.

SD3 No

SD4 When I am thinking of it, I tend to wash my hands with cold water more often now because it is unlikely that the hot water will be

drawn by the end of the use, and there is no sense to heating water that will be unused and left in my pipes.

d) *Have you noticed any occurrences of the "cold water sandwich"? Please describe.*

LA1 45 seconds or more in the upstairs bathrooms

LA4 I notice it in the shower. After someone takes a shower, the hot water should be at the valve. Often a little hot water will come out then cold then hot again. My perception is the water heater sends out some cold water before the coils reheat.

LA5 I have noticed this occurrence when I shave. I tune the hot water on and off and at times the water seem to have cooled off.

PGE1 Not a problem

PGE5 Yes but minor. I insulated all the hot water lines in the house (virtually all but 10' are accessible)

SD1 Yes. We believe that this delay between the initial rinse and the final rinse is due to the water heater cycling off at the end of the initial draw. If there is a delay before the second water draw, we may receive a period of cooler water while the heater activatesmand comes up to speed. I suspect that this effect is increased because we have a long run and the pipes are buried in the slab.

SD3 No

SD4 This has happened when doing dishes a handful of times, typically it is only an issue for a few seconds.

e) *What is your best guess on how much longer you wait for hot water?*

LA1

LA4 Depending on which room we are in, it seems like maybe 30 seconds for the closest and a minute for the longest.

LA5 Not long at all, just about 10 to 15 seconds longer? Not much.

PGE1 Not a noticeable difference-we have to wait a long time anyway

PGE5 We have a Metlund D'mand system. Wait is maybe a minute when using it, closer to 2 minutes if we don't

SD1 I haven't timed it recently, however, I suspect that it is at least 30 seconds or more in the bathroom at the end of the long run.

SD3 About a minute.

SD4 10-15 seconds

f) *Traditionally, standard gas storage water heaters have received little or no maintenance over their lifetimes. Some of the advanced gas water heaters (e.g. tankless) may require more maintenance over their lifetime. Please describe what maintenance activities you anticipate performing and at what interval (annual, every other year, etc.)?*

LA1 None. I want to return to my old setup.

LA2 Not applicable – I did not receive a tankless

LA3 None.

LA4 The plumber told us to change the filter annually. I wasn't aware of additional maintenance requirements.

LA5 The only maintenance I can think of is the filter change. No told me there may be other things I will need to do or have done.

PGE1 I expect to pump vinegar through the unit every once in a while. We have a water softener and I don't know how much this stretches out the service interval. Perhaps once every year and a half or so. Hopefully there won't be many other repairs necessary but I am always wary of advanced systems. More complexity and more moving parts always means more frequent and more complex/costlier repairs.

PGE2 I would most likely inspect the gas line draw twice a year for possible leak and once a year to turn off the water heater to inspect the sediment buildup and remove as necessary.

PGE3 I don't really plan on any normal maintenance activities. But seeing my older heater had a slight leak in it after the plumber removed it I might think about doing some sort of yearly checkup.

PGE4

PGE5 Demineralize heat exchanger. Unit is plumbed to do that.

PGE6

SD1 Based on the advice of the installer and another plumber, I intend to purchase a circulation pump and run vinegar through the tankless water heater at once a year and most likely twice a year. In addition, I will need to replace the filter on the WH and the prefilter on the whole house filtration system on a periodic basis. Given the design of the tankless water heater, it seems much more important to maintain them as compared to a traditional tank heater.

SD2 I do not expect to perform any maintenance.

SD3 The mfg and plumber recommend maintenance every two years. I'm not sure what that includes other than the filter change.

SD4 I plan to have the unit flushed/de-scaled after a year and will base future maintenance cycle on what the initial service finds.

SD5

SD6 I have not had a chance to go over the manual for the new water heater. Doing so would give me a better idea on the additionalmaintenance that needs to be performed. I don't mind the additional maintenance if it helps extend the life of the water heater.

g) *Any final thoughts or comments?*

LA1 What at first seemed like a great idea (save money, never run out of hot water, etc), turned out to be quite the opposite. Maybe it is the type of equipment installed & actual installation, as I have heard great reviews from others using this technology

LA2

LA3 No disappointment at all with the performance. Installation is much more complex with power needs, vent needs, etc. As a result, it may be difficult for DIY'ers to deal with.

LA4 After seeing the amount of extra labor for the retrofit, I'm not convinced the savings on natural gas would ever recoup the expense, especially considering the time value of money. For new installations, it is a great idea!

LA5

PGE1 Given the potential for costly and inconvenient repairs and replacement and the relatively low cost of water heating at this time, I highly doubt that I would have paid full price for this unit and installation. Having the skills to install and maintain/repair it myself makes it much more likely that I would have made the switch on my own but it would be hard for me to recommend to someone without reservations but I have been pleasantly surprised with the performance.

PGE2 The water heater is a great installation to our home. It is nearly constant but I would like to bring to the attention to have the plumbers work out a design and present it to the owners before actually doing the work.

PGE3 Everything seems to be about the same, the only thing I'm not sure about is how efficient the heater actually is. I'd have to check the final report and my previous bills to see what the difference was between the two heaters.

PGE4

PGE5

PGE6 I would like to be able to see if having it has actually resulted in overall reduction in gas & water consumption.

SD1

SD2

SD3

SD4 I am in not totally informed about all the various technologies, and products available for water heating, but from what I have experienced in this pilot, and what I have read about some of the options, if I were to choose a technology to install for myself,I would probably go with a condensing tank-style unit or a hybrid unit where the method of heat transfer does not create create significant additional maintenance. I would also imagine that the condensing tank style units don't require the higher gas gas flow rates, and would not require a new houseline, economizing install costs with minimal or no performance sacrifice. The TWHs seem like a good solution for homes not continuously occupied, or for heavy users who run out of hot water with a standard unit.

SD5

SD6

Appendix N: Baseline and Advanced Water Heater Field Tests Detailed Monitoring Data

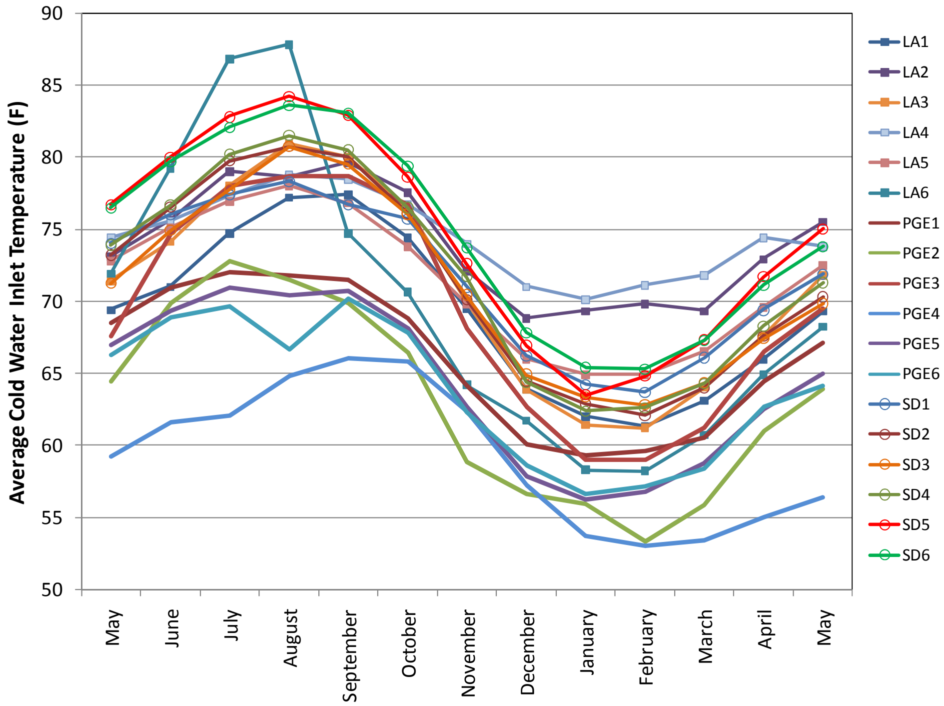


Figure 39: Monthly Average Cold Water Inlet Temperatures by Site

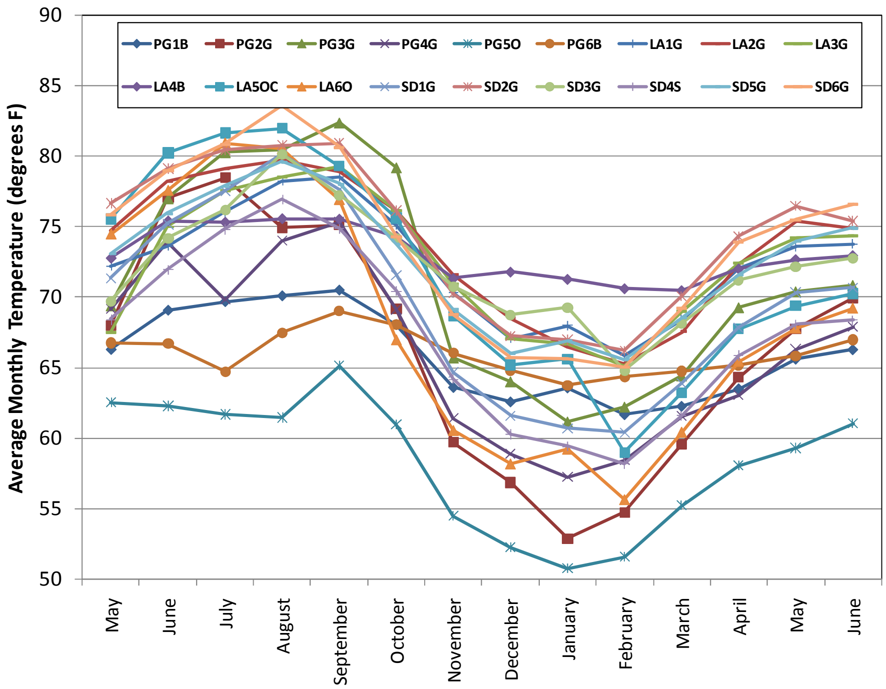


Figure 40: Monthly Average Water Heater Surrounding Environment Temperature by Site

Pre and Post-Retrofit Water Heater Daily Input-Output Data by Site

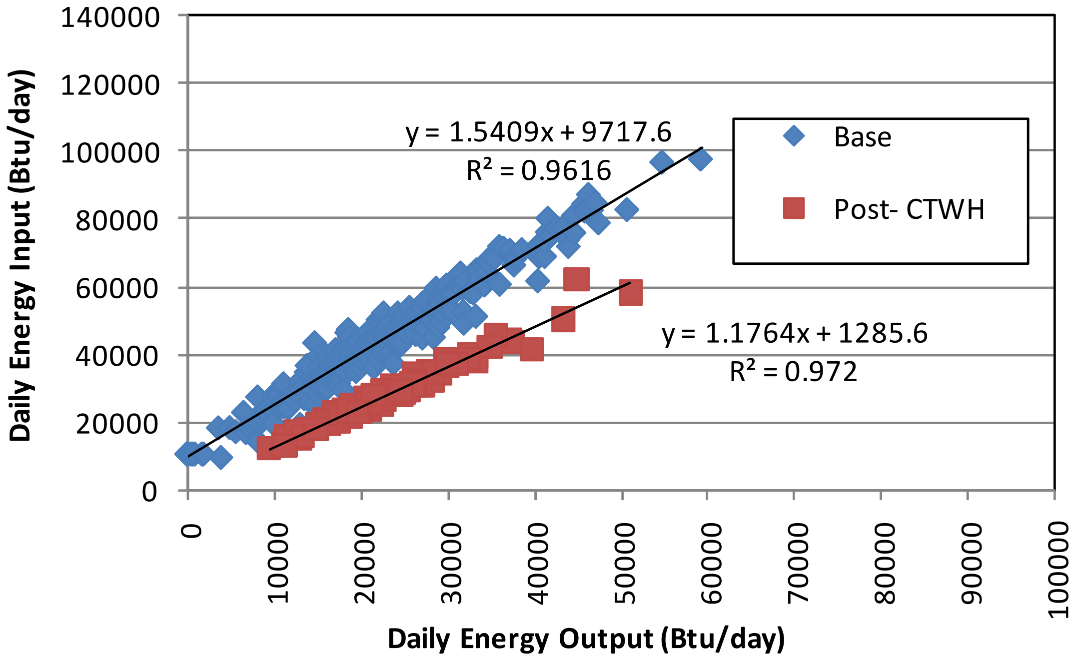


Figure 41: Site PG1

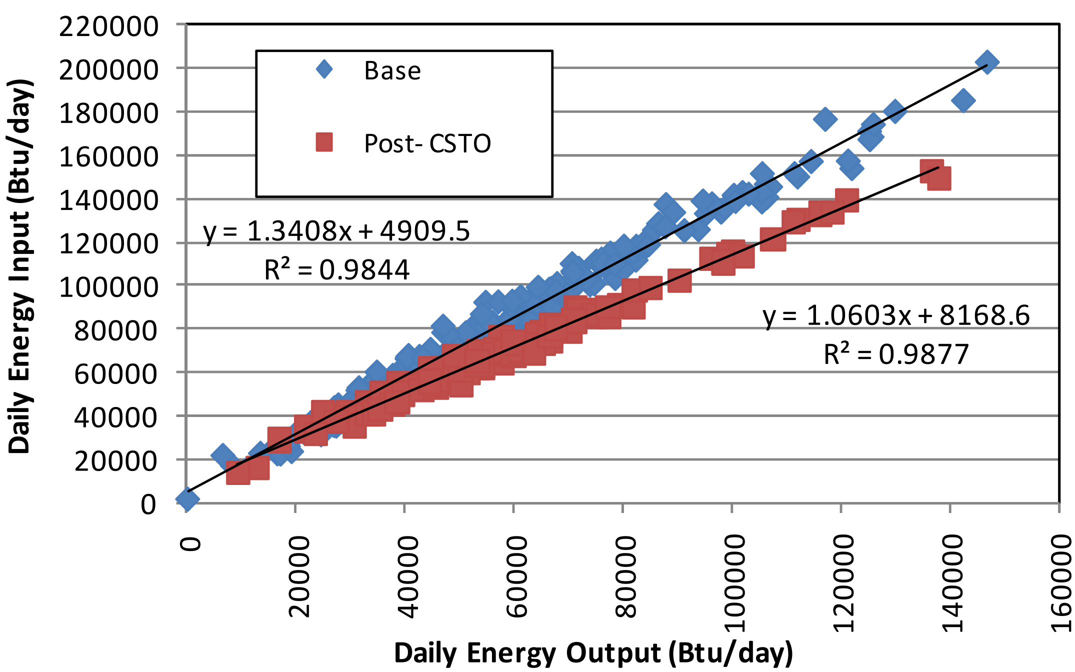


Figure 42: Site PG2

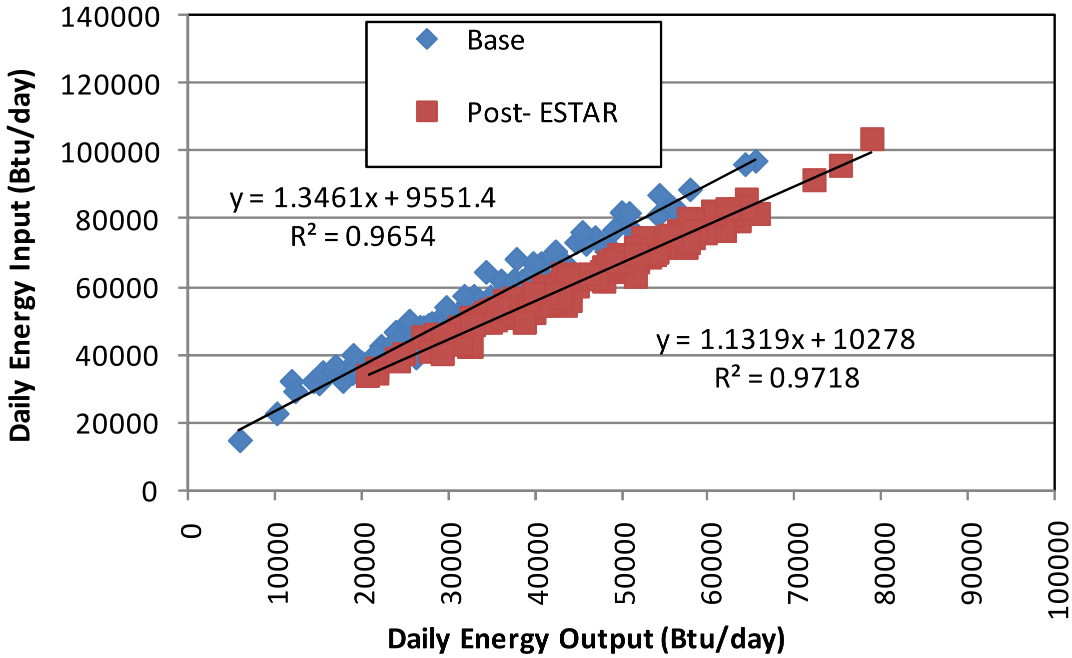


Figure 43: Site PG3

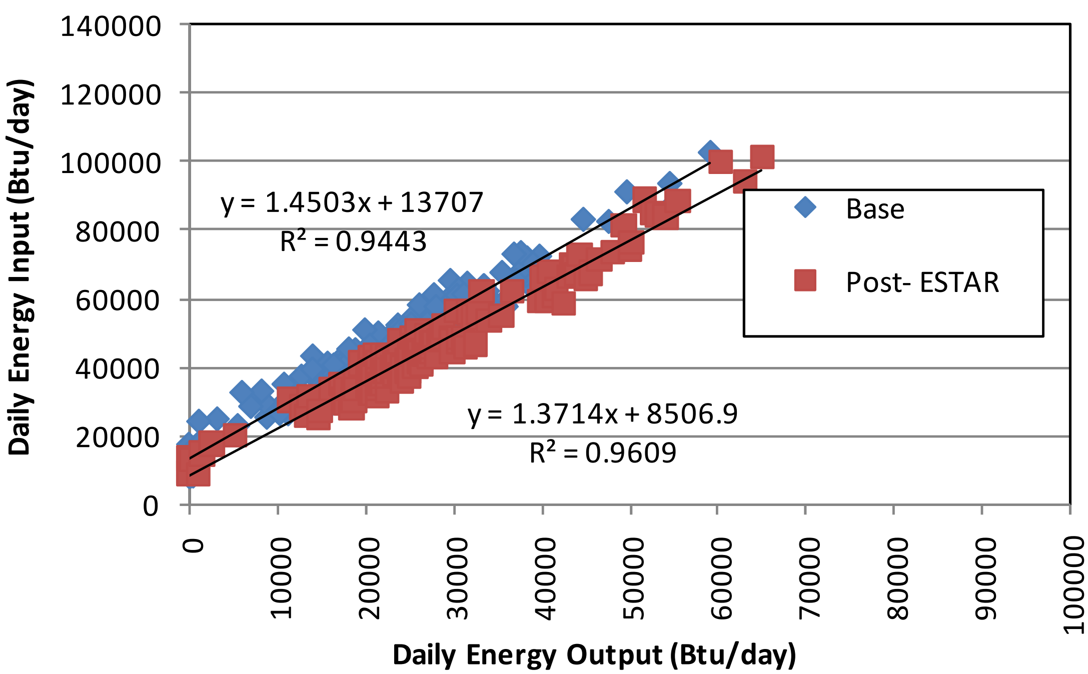


Figure 44: Site PG4

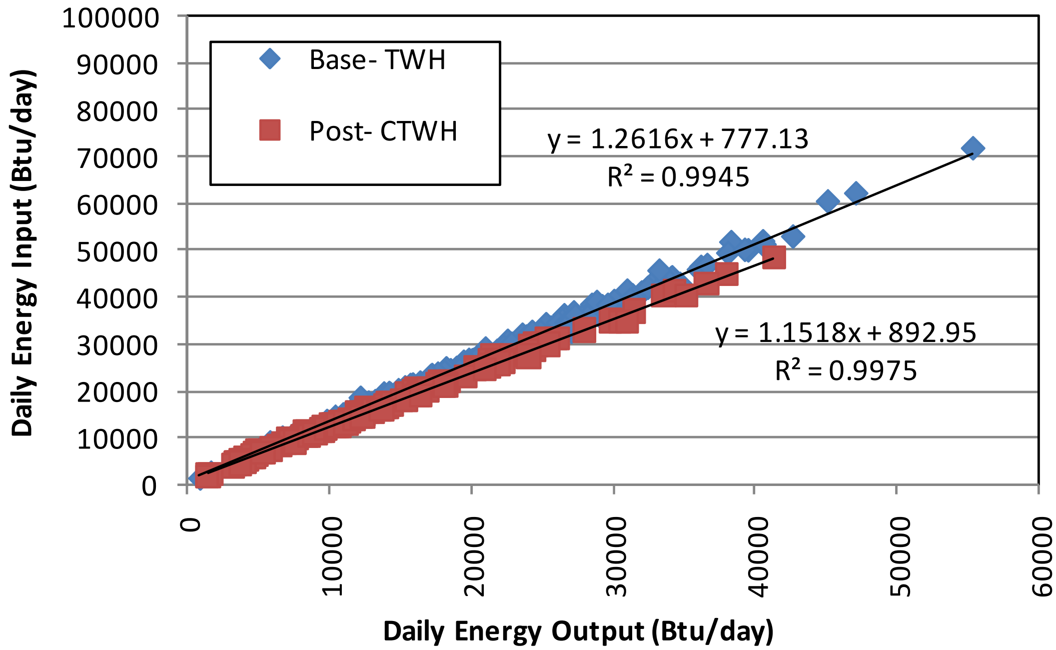


Figure 45: Site PG5

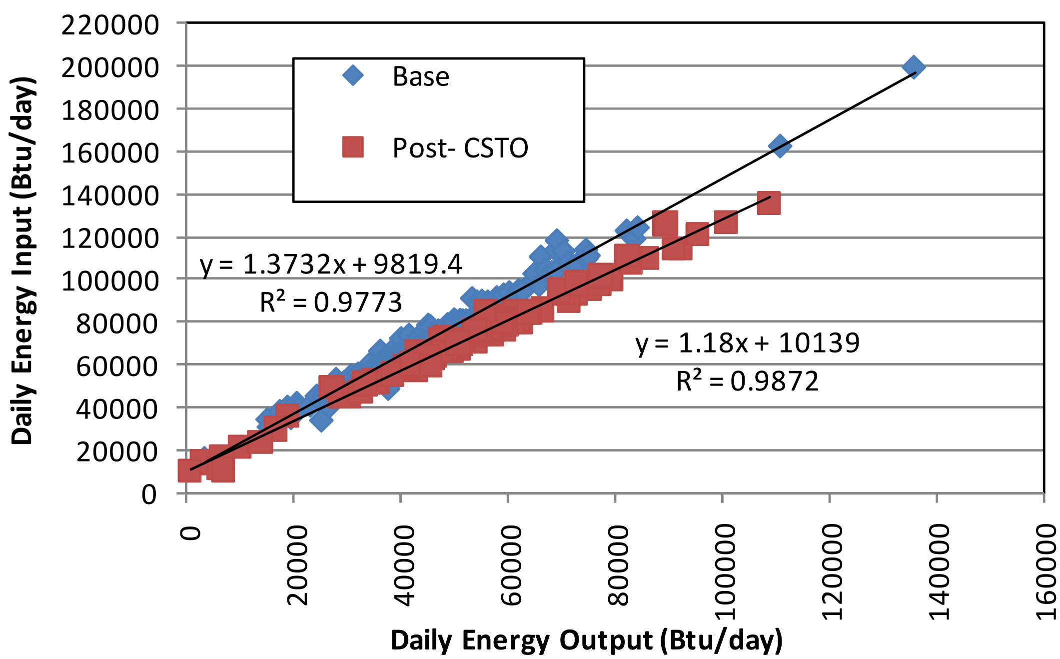


Figure 46: Site PG6

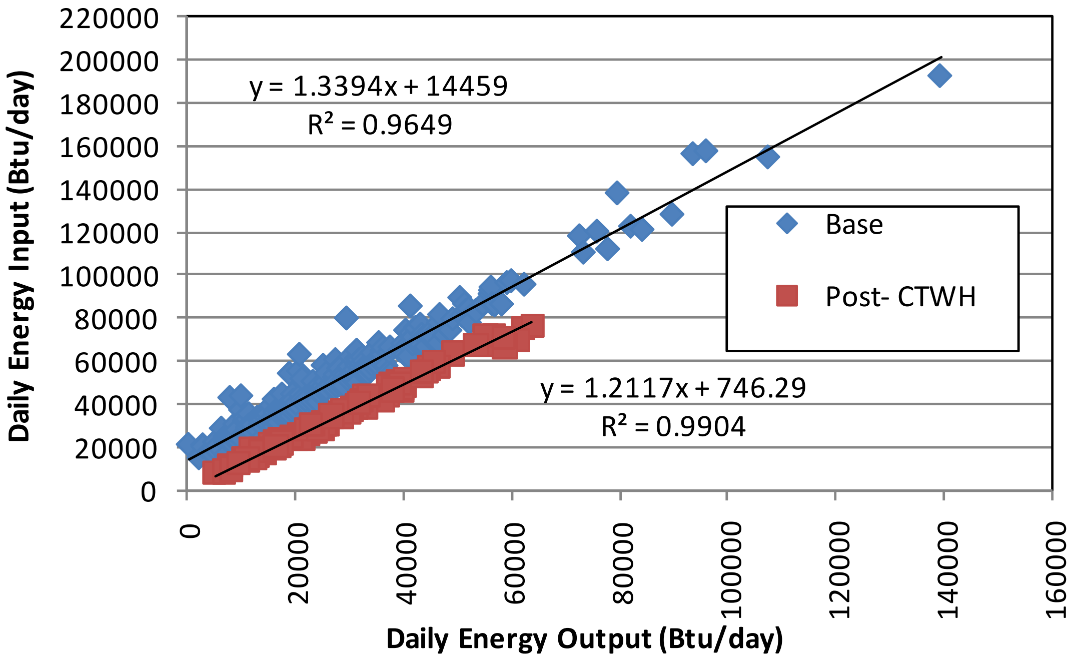


Figure 47: Site LA1

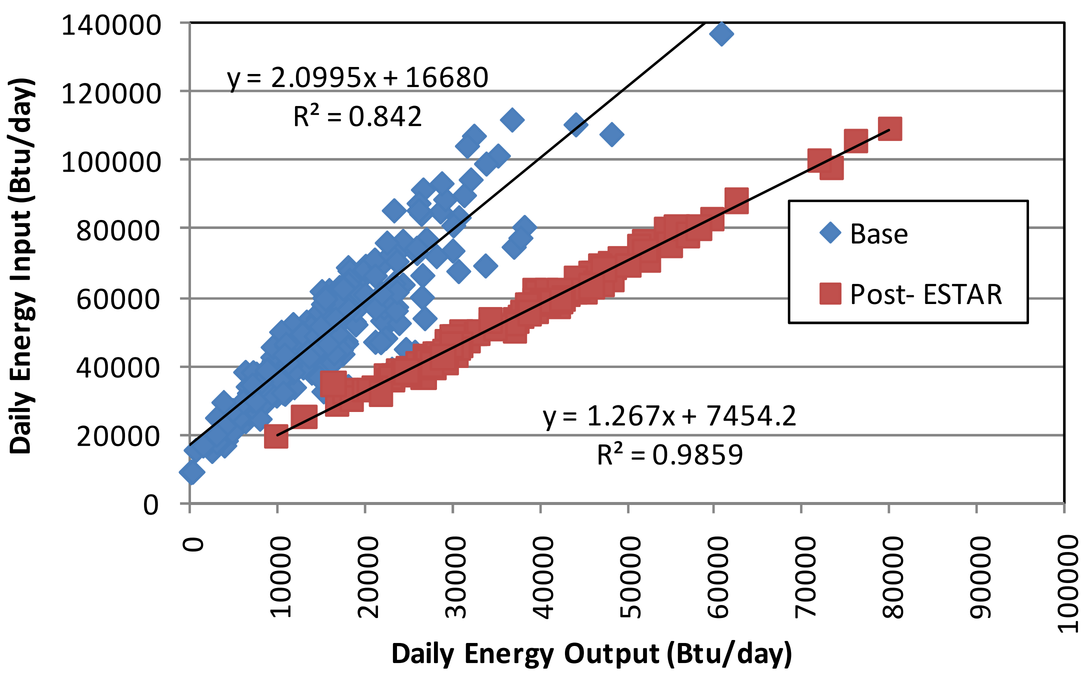


Figure 48: Site LA2

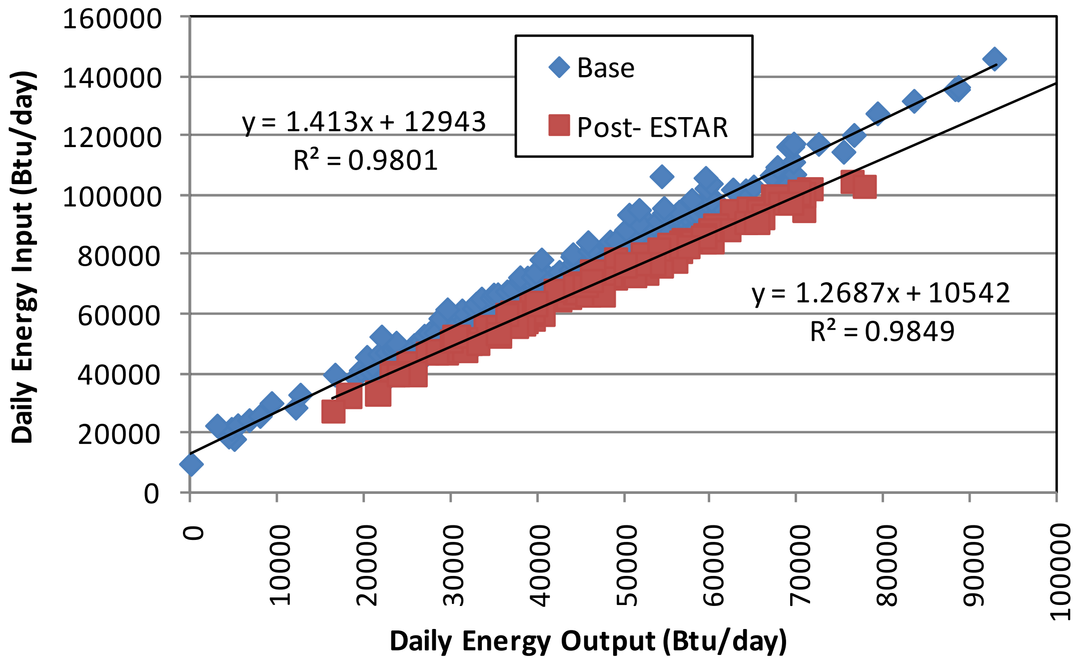


Figure 49: Site LA3

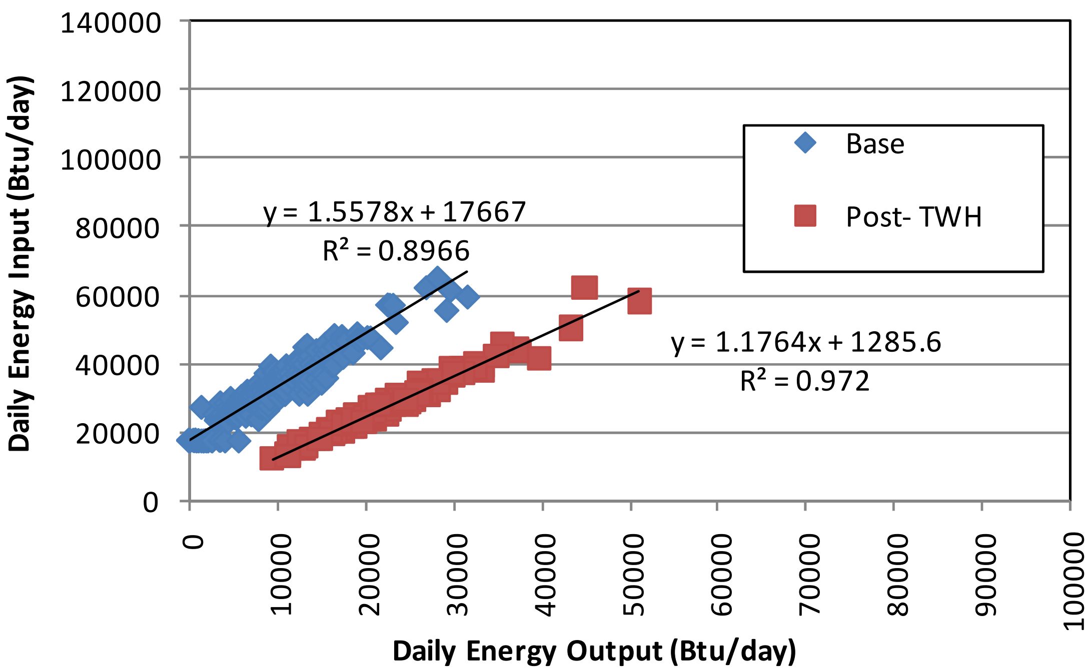


Figure 50: Site LA4

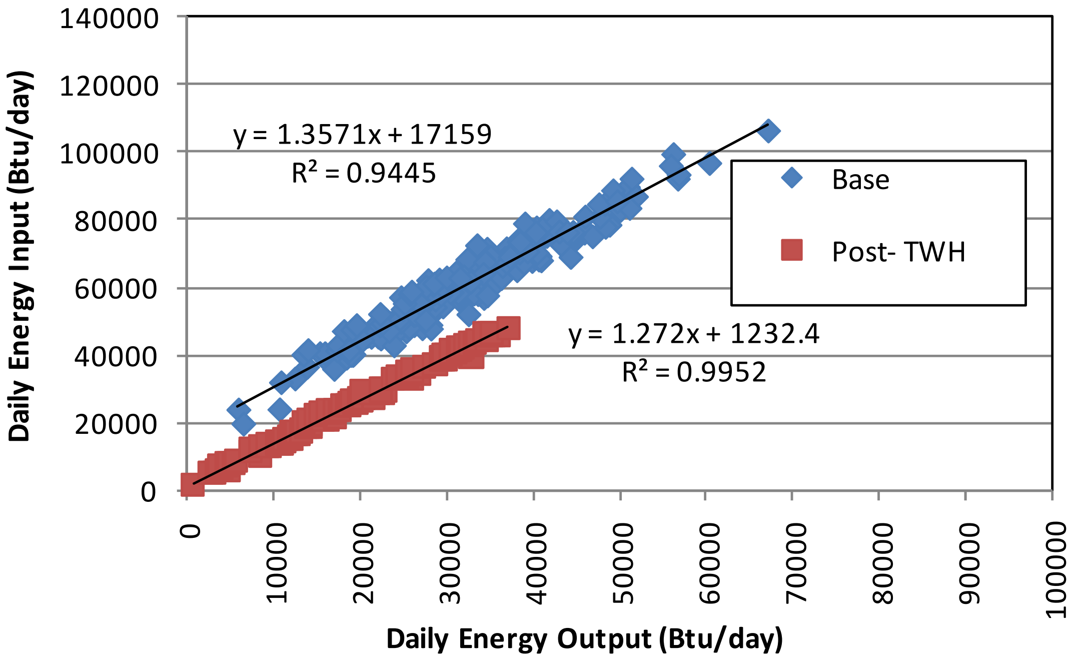


Figure 51: Site LA5

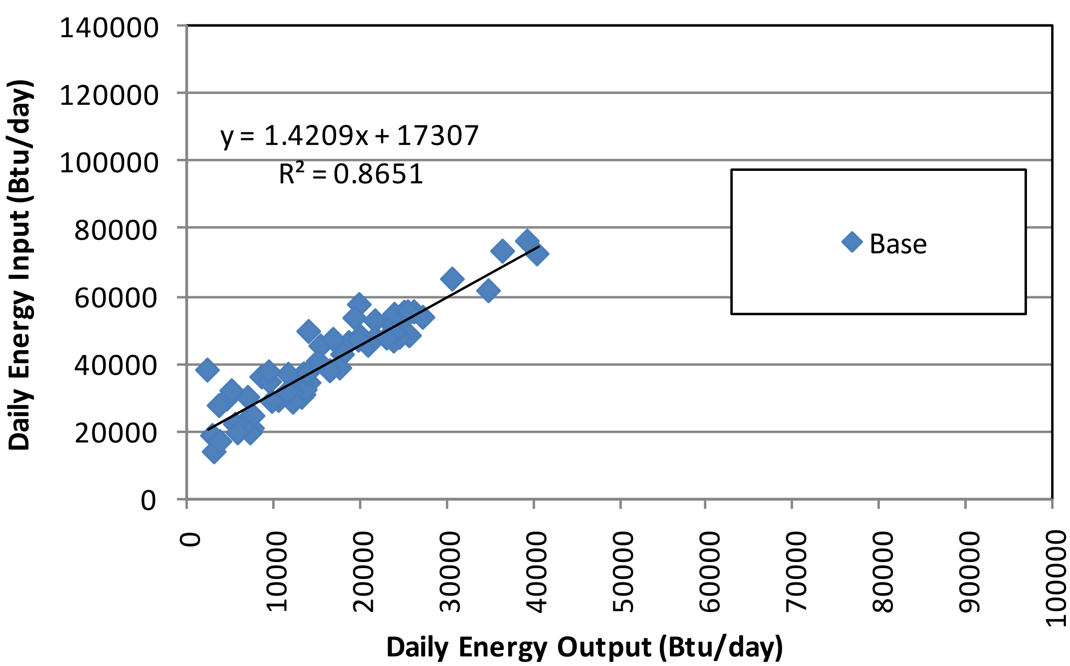


Figure 52: Site LA6

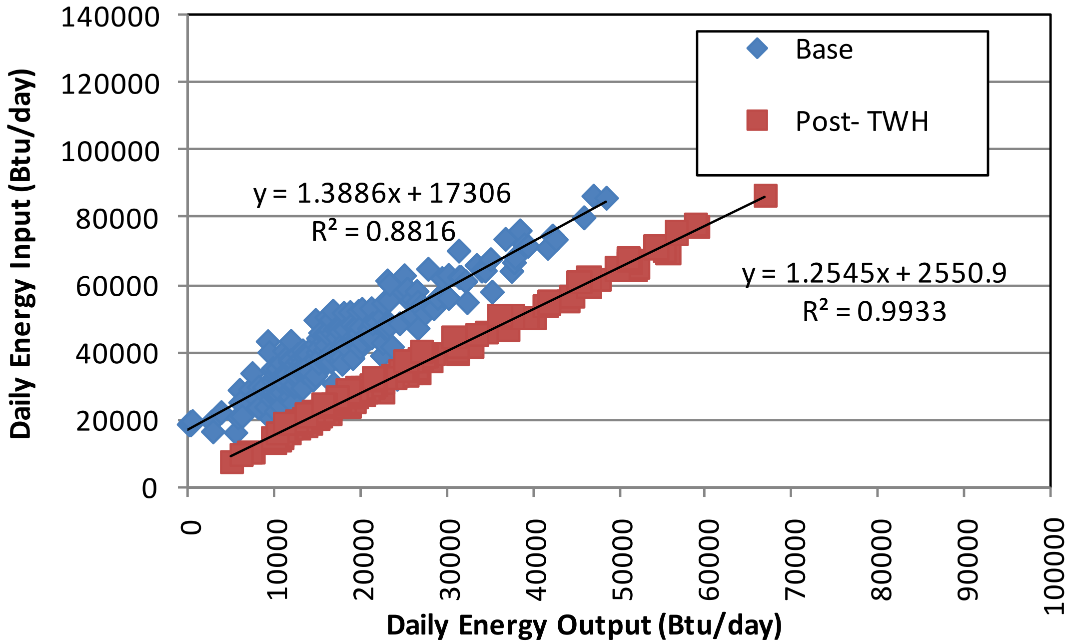


Figure 53: Site SD1

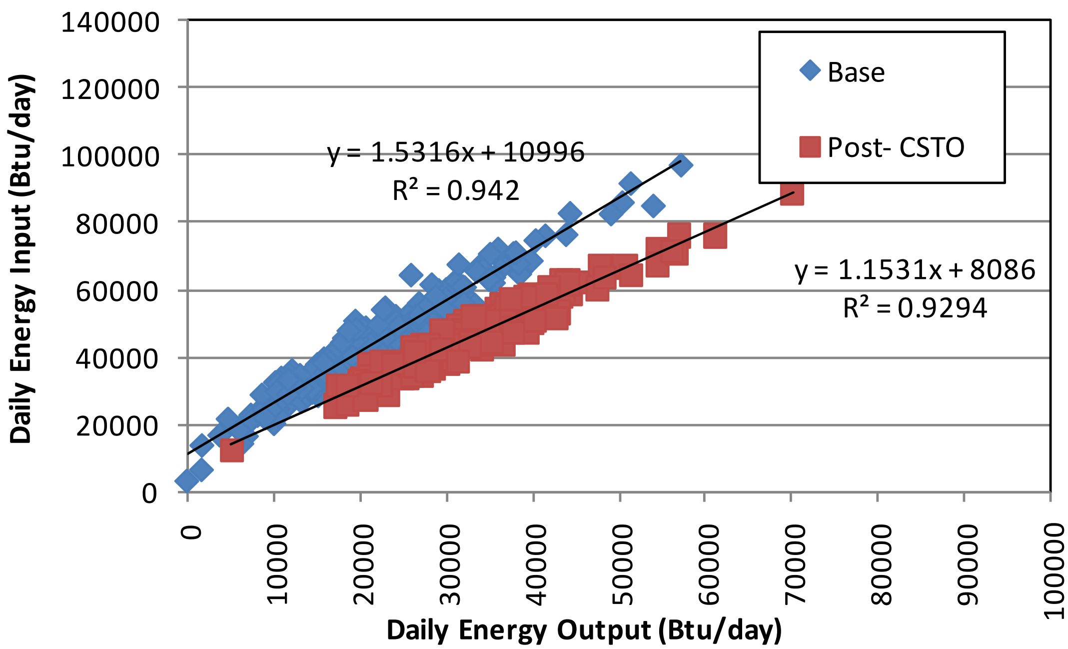


Figure 54: Site SD2

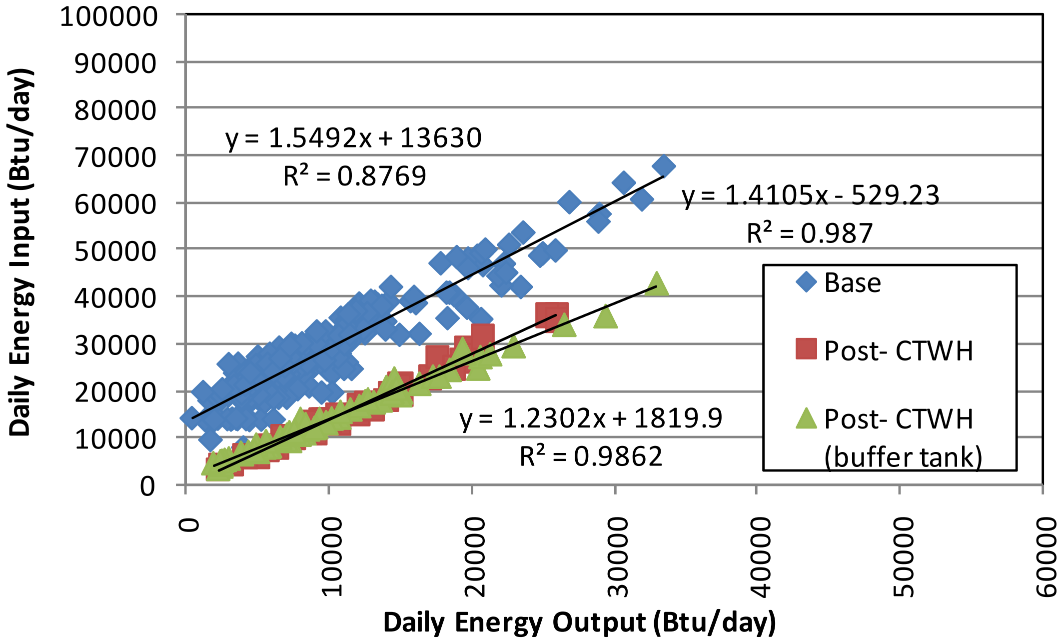


Figure 55: Site SD3

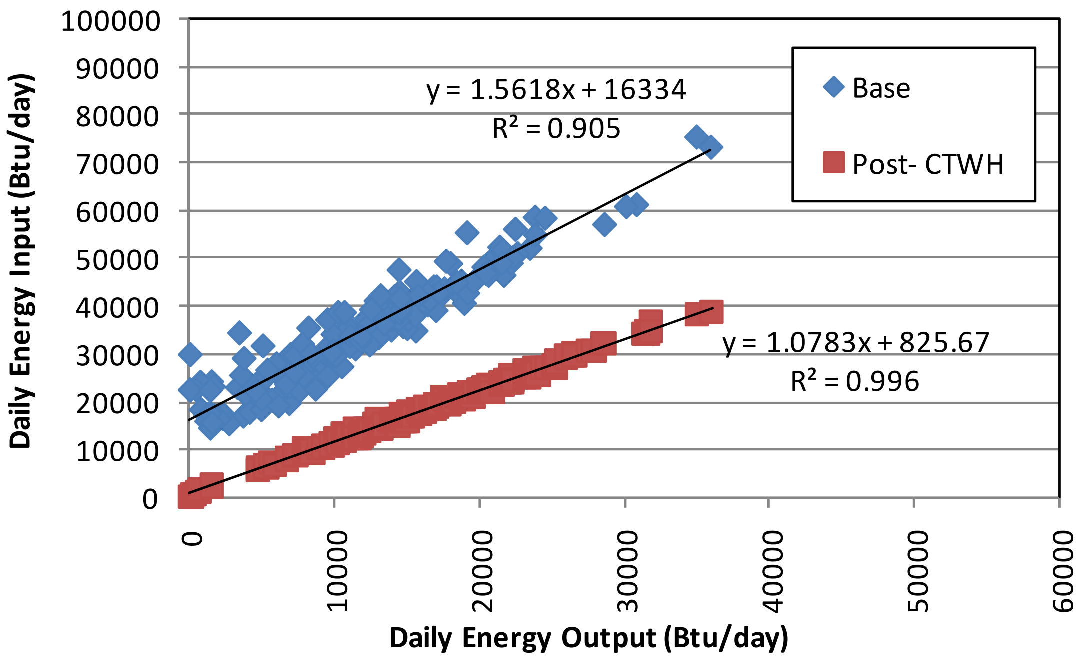


Figure 56: Site SD4

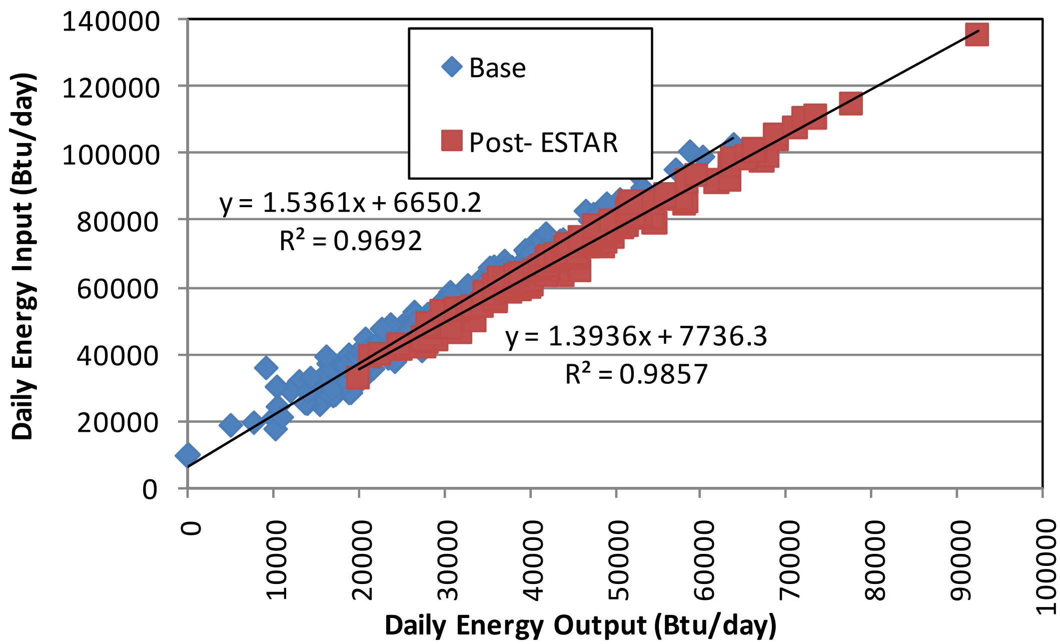


Figure 57: Site SD5

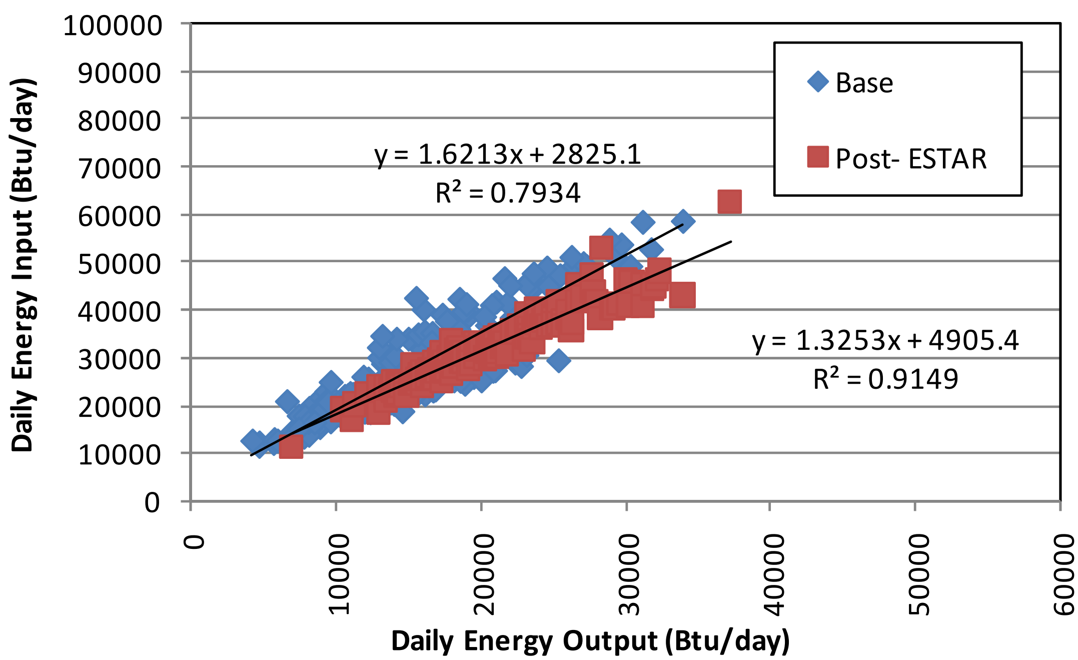


Figure 58: Site SD6

Monthly Summaries

Table 49: Site PGE1

	Daily Average					Monthly Averages				
	Gas Use	Rec Load	Elec Use	Number	Hot Water	"EF"	"EF"	Gas Btu/	HW gal/	HW gal/
	therms	therms*	kWh	of draws	(HW) gals	Gas only	Site	gal HW	therm	draw
April	0.45	0.25	0.00	65.0	69.5	0.56	0.56	710	156	1.07
May	0.36	0.18	0.00	41.5	51.1	0.49	0.49	701	143	1.23
June	0.33	0.15	0.01	38.1	48.4	0.47	0.47	676	148	1.27
July	0.30	0.14	0.00	29.6	44.5	0.46	0.46	664	150	1.51
August	0.38	0.19	0.00	41.2	65.3	0.50	0.50	595	174	1.58
September	0.32	0.15	0.00	25.1	51.1	0.47	0.47	619	162	2.04
October	0.42	0.21	0.00	37.8	62.2	0.50	0.50	674	148	1.64
November	0.50	0.31	0.00	35.8	61.7	0.61	0.61	810	123	1.72
December	0.59	0.31	0.00	39.2	66.0	0.52	0.52	894	112	1.68
January	0.63	0.34	0.00	44.4	73.5	0.54	0.54	854	117	1.66
Febuary	0.53	0.27	0.00	28.5	64.4	0.52	0.52	820	122	2.26
Feb Retro	0.32	0.27	0.25	29.8	62.3	0.82	0.80	488	192	2.10
March	0.32	0.27	0.28	32.0	68.3	0.83	0.81	471	212	2.14
April	0.24	0.20	0.27	24.4	52.5	0.81	0.78	462	217	2.15
May	0.27	0.21	0.28	32.1	60.0	0.78	0.75	442	226	1.87
June	0.19	0.15	0.26	23.6	44.4	0.78	0.74	435	230	1.88

* recovery load presented in terms of 100,000 Btu/day

Table 50: Site PGE2

	Daily Average					Monthly Averages				
	Gas Use therms	Rec Load therms*	Elec Use kWh	Number of draws	Hot Water (HW) gals	"EF" Gas only	"EF" Site	Gas Btu/ gal HW	HW gal/ therm	HW gal/ draw
May	0.75	0.51	0.00	102.6	135.5	0.67	0.67	555	180	1.32
June	0.55	0.38	0.00	114.7	123.1	0.69	0.69	443	226	1.07
July	0.48	0.34	0.00	95.9	126.7	0.70	0.70	377	265	1.32
August	0.57	0.41	0.00	101.2	146.8	0.71	0.71	405	256	1.45
September	0.52	0.38	0.00	92.0	143.3	0.72	0.72	435	276	1.56
October	0.72	0.51	0.00	101.4	145.3	0.72	0.72	494	203	1.43
November	0.92	0.65	0.00	102.7	145.3	0.70	0.70	637	157	1.41
December	1.00	0.71	0.00	106.0	164.5	0.71	0.71	678	165	1.55
January	1.14	0.79	0.00	113.4	148.8	0.69	0.69	769	130	1.31
February	1.11	0.76	0.00	115.8	123.2	0.68	0.68	903	111	1.06
March retro	0.75	0.61	0.22	98.5	134.1	0.82	0.81	595	180	1.36
April	0.74	0.64	0.22	126.1	146.5	0.86	0.85	507	197	1.16
May	0.70	0.59	0.22	122.3	143.0	0.84	0.84	490	204	1.17
June	0.51	0.40	0.21	98.7	106.7	0.80	0.79	476	210	1.08

* recovery load presented in terms of 100,000 Btu/day

Table 51: Site PGE3

	Daily Average					Monthly Averages				
	Gas Use therms	Rec Load therms*	Elec Use kWh	Number of draws	Hot Water gallons	"EF" Gas only	"EF" Site	Gas Btu/ gal HW	HW gal/ therm	HW gal/ draw
May	0.52	0.31	0.00	20.6	67.0	0.60	0.60	884	128	3.25
June	0.36	0.20	0.00	12.3	44.1	0.57	0.57	855	123	3.60
July	0.41	0.24	0.00	16.3	54.1	0.58	0.58	792	132	3.32
August	0.46	0.27	0.00	16.5	60.2	0.58	0.58	758	132	3.64
September	0.45	0.27	0.00	17.7	64.5	0.61	0.61	714	145	3.64
October	0.47	0.29	0.00	16.0	65.1	0.61	0.61	763	137	4.08
November	0.67	0.41	0.00	18.0	77.7	0.62	0.62	895	117	4.32
December	0.76	0.50	0.00	17.5	84.9	0.65	0.65	899	111	4.85
Jan Retro	0.66	0.49	0.33	18.3	85.0	0.75	0.73	770	130	4.65
February	0.65	0.49	0.32	18.2	84.9	0.75	0.74	764	131	4.66
March	0.69	0.51	0.34	20.5	84.3	0.75	0.73	813	123	4.10
April	0.61	0.45	0.31	21.6	78.3	0.74	0.72	780	128	3.63
May	0.54	0.39	0.29	17.0	69.4	0.72	0.70	780	128	4.09
June	0.53	0.38	0.28	19.5	68.9	0.72	0.70	769	130	3.54

* recovery load presented in terms of 100,000 Btu/day

Table 52: Site PGE4

	Daily Average					Monthly Averages				
	Gas Use therms	Rec Load therms *	Elec Use kWh	Number of draws	Hot Water (HW) gals	"EF" Gas only	"EF" Site	Gas Btu/ gal HW	HW gal/ therm	HW gal/ draw
May	0.52	0.29	0.00	31.6	51.9	0.55	0.55	1005	99	1.64
June	0.44	0.21	0.00	17.6	39.4	0.47	0.47	1104	91	2.24
July	0.39	0.18	0.00	14.9	38.1	0.46	0.46	1112	97	2.56
August	0.44	0.21	0.00	17.6	42.6	0.49	0.49	1031	97	2.42
September	0.38	0.19	0.00	17.1	39.0	0.50	0.50	962	104	2.28
October	0.48	0.24	0.00	19.5	48.6	0.50	0.50	979	102	2.49
November	0.45	0.21	0.00	17.5	47.9	0.46	0.46	943	106	2.73
December	0.45	0.21	0.00	17.5	48.4	0.47	0.47	939	106	2.76
January	0.56	0.28	0.00	24.0	59.8	0.49	0.49	943	106	2.49
Jan Retro	0.55	0.31	0.00	27.6	41.7	0.57	0.57	1327	75	1.51
February	0.54	0.32	0.20	21.1	46.7	0.60	0.59	1153	87	2.21
March	0.42	0.24	0.18	12.6	36.2	0.58	0.57	1149	87	2.87
April	0.37	0.21	0.17	12.7	33.6	0.56	0.55	1087	92	2.65
May	0.36	0.22	0.17	16.3	40.2	0.60	0.59	902	111	2.46
June	0.35	0.22	0.16	13.8	38.8	0.62	0.61	904	111	2.80

* recovery load presented in terms of 100,000 Btu/day

Table 53: Site PGE5

	Daily Average					Monthly Averages				
	Gas Use	Rec Load	Elec Use	Number	Hot Water	"EF"	"EF"	Gas Btu/	HW gal/	HW gal/
	therms	therms*	kWh	of draws	(HW) gals	Gas only	Site	gal HW	therm	draw
May	0.24	0.18	0.15	20.8	58.8	0.76	0.75	402	249	2.83
June	0.29	0.22	0.17	22.4	64.0	0.77	0.76	453	221	2.86
July	0.28	0.21	0.17	21.6	58.0	0.77	0.75	479	209	2.68
August	0.24	0.19	0.16	18.9	50.4	0.76	0.75	481	208	2.67
September	0.26	0.20	0.16	21.4	55.1	0.78	0.76	469	213	2.58
October	0.29	0.23	0.16	19.3	62.6	0.79	0.77	463	216	3.24
November	0.35	0.27	0.17	23.1	63.7	0.77	0.76	550	182	2.75
December	0.29	0.22	0.16	18.1	47.7	0.77	0.75	613	163	2.64
January	0.20	0.15	0.16	14.9	32.0	0.75	0.73	628	159	2.16
Jan Retro	0.21	0.18	0.08	15.5	36.7	0.84	0.83	577	173	2.36
February	0.20	0.16	0.09	13.2	33.5	0.83	0.82	587	170	2.53
March	0.17	0.13	0.07	12.2	28.3	0.74	0.73	601	166	2.32
April	0.17	0.14	0.07	14.3	32.2	0.82	0.81	534	187	2.25
May	0.16	0.13	0.07	13.4	30.5	0.81	0.80	513	195	2.28
June	0.12	0.09	0.07	9.6	22.7	0.80	0.79	517	193	2.35

* recovery load presented in terms of 100,000 Btu/day

Table 54: Site PGE6

	Daily Average					Monthly Averages				
	Gas Use therms	Rec Load therms*	Elec Use kWh	Number of draws	Hot Water (HW) gals	"EF" Gas only	"EF" Site	Gas Btu/ gal HW	HW gal/ therm	HW gal/ draw
May	0.64	0.40	0.00	44.0	92.0	0.62	0.62	698	143	2.09
June	0.63	0.38	0.00	37.8	94.5	0.61	0.61	666	150	2.50
July	0.66	0.40	0.00	41.0	98.4	0.61	0.61	667	150	2.40
August	0.66	0.41	0.00	45.7	104.3	0.62	0.62	630	159	2.28
September	0.61	0.38	0.00	31.7	97.3	0.62	0.62	622	161	3.07
October	0.64	0.40	0.00	37.3	97.5	0.62	0.62	658	152	2.62
November	0.80	0.51	0.00	51.9	110.7	0.64	0.64	723	138	2.13
December	0.79	0.50	0.00	44.6	103.3	0.64	0.64	765	131	2.32
January	0.91	0.59	0.00	47.5	117.7	0.65	0.65	777	129	2.48
Jan Retro	0.88	0.67	0.61	41.3	116.9	0.76	0.74	749	133	2.83
February	0.83	0.63	0.60	41.6	108.1	0.76	0.74	765	131	2.60
March	0.67	0.45	0.55	37.7	85.2	0.67	0.65	790	127	2.26
April	0.67	0.48	0.57	40.9	90.2	0.71	0.69	745	134	2.21
May	0.67	0.48	0.59	44.3	91.8	0.71	0.69	734	136	2.07
June	0.65	0.46	0.60	47.2	89.6	0.71	0.69	721	139	1.90

* recovery load presented in terms of 100,000 Btu/day

Table 55: Site LA1

	Daily Average					Monthly Averages				
	Gas Use	Rec Load	Elec Use	Number	Hot Water	"EF"	"EF"	Gas Btu/	HW gal/	HW gal/
	therms	therms*	kWh	of draws	(HW) gals	Gas only	Site	gal HW	therm	draw
May	0.68	0.30	0.00	41.1	83.0	0.44	0.44	814	123	2.02
June	0.54	0.30	0.00	51.2	76.5	0.56	0.56	707	141	1.49
July	0.45	0.24	0.00	40.8	68.2	0.54	0.54	660	152	1.67
August	0.37	0.19	0.00	34.1	56.9	0.51	0.51	646	155	1.67
September	0.47	0.24	0.00	34.1	72.1	0.52	0.52	645	155	2.11
October	0.50	0.27	0.00	38.2	73.9	0.54	0.54	674	148	1.94
November	0.50	0.25	0.00	29.6	60.9	0.50	0.50	813	123	2.06
December	0.82	0.47	0.00	53.2	103.3	0.57	0.57	798	125	1.94
January	0.65	0.36	0.00	33.2	75.7	0.55	0.55	857	117	2.28
Feb Retro	0.46	0.28	0.32	23.8	60.2	0.62	0.60	756	132	2.53
March	0.41	0.34	0.31	35.3	71.1	0.82	0.80	579	173	2.01
April	0.34	0.27	0.31	34.3	61.2	0.81	0.78	552	181	1.78
May	0.34	0.27	0.32	31.1	64.5	0.80	0.77	527	190	2.08
June	0.30	0.24	0.28	22.7	59.2	0.81	0.78	511	196	2.61

* recovery load presented in terms of 100,000 Btu/day

Table 56: Site LA2

	Daily Average					Monthly Averages				
	Gas Use	Rec Load	Elec Use	Number	Hot Water	"EF"	"EF"	Gas Btu/	HW gal/	HW gal/
	therms	therms*	kWh	of draws	(HW) gals	Gas only	Site	gal HW	therm	draw
May	0.51	*0.24*	*0.00*	*39.2*	*58.9*	*0.48*	*0.48*	*871*	*115*	*1.50*
June	0.45	*0.17*	*0.00*	*32.1*	*41.8*	*0.38*	*0.38*	*1077*	*93*	*1.30*
July	0.40	*0.12*	*0.00*	*33.2*	*32.1*	*0.30*	*0.30*	*1246*	*80*	*0.97*
August	0.44	*0.11*	*0.00*	*27.1*	*31.1*	*0.26*	*0.26*	*1415*	*71*	*1.15*
September	0.42	*0.12*	*0.00*	*27.5*	*32.2*	*0.28*	*0.28*	*1300*	*77*	*1.17*
October	0.45	*0.14*	*0.00*	*23.8*	*38.1*	*0.31*	*0.31*	*1181*	*85*	*1.60*
November	0.53	*0.16*	*0.00*	*31.2*	*35.4*	*0.30*	*0.30*	*1483*	*67*	*1.13*
December	0.63	*0.20*	*0.00*	*25.9*	*42.7*	*0.31*	*0.31*	*1480*	*68*	*1.65*
January	0.59	*0.18*	*0.00*	*25.5*	*39.0*	*0.31*	*0.31*	*1524*	*66*	*1.53*
Feb Retro	0.72	0.50	0.38	113.2	106.3	0.69	0.68	674	148	0.94
March	0.56	0.38	0.31	80.6	81.6	0.68	0.67	691	145	1.01
April	0.53	0.36	0.29	92.9	83.5	0.68	0.67	633	158	0.90
May	0.45	0.30	0.25	79.3	74.1	0.67	0.66	610	164	0.93

* recovery load presented in terms of 100,000 Btu/day

Data has questionable hot water flow data

Table 57: Site LA3

	Daily Average					Monthly Averages				
	Gas Use	Rec Load	Elec Use	Number	Hot Water	"EF"	"EF"	Gas Btu/	HW gal/	HW gal/
	therms	therms*	kWh	of draws	(HW) gals	Gas only	Site	gal HW	therm	draw
May	0.75	0.44	0.00	54.4	79.5	0.58	0.58	949	105	1.46
June	0.73	0.43	0.00	50.0	83.7	0.59	0.59	875	114	1.67
July	0.67	0.39	0.00	49.2	81.3	0.58	0.58	823	121	1.65
August	0.44	0.22	0.00	29.8	50.9	0.51	0.51	863	116	1.71
September	0.59	0.34	0.00	38.9	73.8	0.57	0.57	804	124	1.90
October	0.67	0.39	0.00	34.2	78.2	0.58	0.58	861	116	2.29
November	0.76	0.44	0.00	38.8	79.7	0.58	0.58	957	104	2.05
December	0.94	0.56	0.00	45.5	90.7	0.60	0.60	1031	97	1.99
January	0.92	0.55	0.00	44.7	84.5	0.60	0.60	1087	92	1.89
Feb Retro	0.86	0.59	0.43	38.2	84.1	0.69	0.68	1017	98	2.20
March	0.76	0.52	0.39	40.4	74.6	0.68	0.66	1024	98	1.85
April	0.67	0.45	0.34	35.7	67.9	0.67	0.66	991	101	1.90
May	0.59	0.39	0.31	35.3	62.1	0.65	0.64	958	104	1.76
June	0.59	0.39	0.31	37.5	63.9	0.66	0.65	925	108	1.70

* recovery load presented in terms of 100,000 Btu/day

Table 58: Site LA4

	Daily Average					Monthly Averages				
	Gas Use therms	Rec Load therms*	Elec Use kWh	Number of draws	Hot Water (HW) gals	"EF" Gas only	"EF" Site	Gas Btu/ gal HW	HW gal/ therm	HW gal/ draw
May	0.29	0.07	0.00	10.4	15.1	0.24	0.24	1944	51	1.46
June	0.34	0.11	0.00	17.1	23.8	0.33	0.33	1425	70	1.39
July	0.31	0.09	0.00	15.8	20.4	0.29	0.29	1502	67	1.29
August	0.29	0.08	0.00	13.8	18.2	0.26	0.26	1604	62	1.32
September	0.30	0.08	0.00	14.0	17.8	0.26	0.26	1662	60	1.27
October	0.29	0.07	0.00	13.0	16.5	0.25	0.25	1764	57	1.27
November	0.36	0.11	0.00	20.6	24.0	0.31	0.31	1511	66	1.16
December	0.32	0.09	0.00	15.4	18.6	0.28	0.28	1717	58	1.21
January	0.34	0.11	0.00	17.6	23.2	0.31	0.31	1485	67	1.32
February	0.32	0.08	0.00	15.8	17.4	0.26	0.26	1808	55	1.10
Feb Retro	0.13	0.08	0.10	11.2	19.2	0.67	0.65	655	153	1.71
March	0.12	0.08	0.10	12.7	18.8	0.66	0.64	651	154	1.48
April	0.15	0.10	0.10	12.3	23.6	0.68	0.67	616	162	1.91
May	0.15	0.10	0.10	13.2	23.8	0.68	0.67	620	161	1.80
June	0.18	0.13	0.10	14.5	29.6	0.70	0.69	604	166	2.04

* recovery load presented in terms of 100,000 Btu/day

Table 59: Site LA5

	Daily Average					Monthly Averages				
	Gas Use therms	Rec Load therms*	Elec Use kWh	Number of draws	Hot Water (HW) gals	"EF" Gas only	"EF" Site	Gas Btu/ gal HW	HW gal/ therm	HW gal/ draw
May	0.65	0.38	0.00	87.1	66.2	0.58	0.58	987	101	0.76
June	0.59	0.33	0.00	55.4	58.3	0.55	0.55	1016	98	1.05
July	0.46	0.22	0.00	45.2	42.1	0.49	0.49	1095	91	0.93
August	0.50	0.25	0.00	49.7	46.9	0.51	0.51	1064	94	0.94
September	0.50	0.26	0.00	55.3	46.6	0.53	0.53	1072	93	0.84
October	0.59	0.30	0.00	43.3	52.5	0.51	0.51	1128	89	1.21
November	0.69	0.37	0.00	55.5	60.3	0.53	0.53	1139	88	1.09
December	0.71	0.38	0.00	52.6	61.9	0.53	0.53	1181	88	1.18
January	0.67	0.35	0.00	45.8	52.7	0.52	0.52	1267	79	1.15
Feb Retro	0.45	0.34	0.14	33.3	77.3	0.76	0.75	584	171	2.32
March	0.41	0.31	0.14	29.3	72.1	0.76	0.75	572	175	2.46
April	0.19	0.14	0.13	20.7	35.1	0.72	0.70	544	184	1.69
May	0.20	0.15	0.12	15.4	39.2	0.75	0.73	512	195	2.55

* recovery load presented in terms of 100,000 Btu/day

Table 60: Site LA6

	Daily Average					Monthly Averages				
	Gas Use	Rec Load	Elec Use	Number	Hot Water	"EF"	"EF"	Gas Btu/	HW gal/	HW gal/
	therms	therms*	kWh	of draws	(HW) gals	Gas only	Site	gal HW	therm	draw
May	0.51	0.19	0.00	26.3	35.9	0.36	0.36	1415	71	1.37
June	0.44	0.12	0.00	25.5	26.7	0.25	0.25	1642	61	1.05
July	0.34	0.07	0.00	14.0	18.4	0.18	0.18	1822	55	1.32
August	0.36	0.05	0.00	14.0	15.0	0.13	0.13	2421	41	1.07
September	0.45	0.09	0.00	17.2	20.3	0.17	0.17	2230	45	1.18
October	0.48	0.10	0.00	14.6	22.1	0.19	0.19	2187	46	1.51
November	0.56	0.10	0.00	20.5	20.7	0.16	0.16	2731	37	1.01
December	0.66	0.13	0.00	28.0	24.7	0.19	0.19	2685	37	0.88
January	0.78	0.18	0.00	28.0	32.7	0.23	0.23	2876	42	1.17
February	0.57	0.08	0.00	17.1	15.6	0.13	0.13	3641	27	0.91
March	0.52	0.18	0.00	14.6	33.1	0.36	0.36	1806	64	2.27
April	0.40	0.15	0.00	13.4	27.3	0.37	0.37	1449	69	2.04
May	0.34	0.11	0.00	7.1	21.3	0.31	0.31	1601	62	2.98

* recovery load presented in terms of 100,000 Btu/day

Table 61: Site SD1

	Daily Average					Monthly Averages				
	Gas Use therms	Rec Load therms*	Elec Use kWh	Number of draws	Hot Water (HW) gals	"EF" Gas only	"EF" Site	Gas Btu/ gal HW	HW gal/ therm	HW gal/ draw
May	0.43	0.17	0.00	37.3	28.6	0.39	0.39	1506	66	0.77
June	0.42	0.18	0.00	34.9	32.2	0.44	0.44	1299	77	0.92
July	0.32	0.13	0.00	30.8	25.1	0.40	0.40	1263	79	0.82
August	0.36	0.16	0.00	38.1	29.2	0.44	0.44	1264	82	0.77
September	0.34	0.14	0.00	34.5	29.1	0.43	0.43	1162	86	0.84
October	0.44	0.19	0.00	35.3	36.1	0.45	0.45	1208	83	1.02
November	0.48	0.19	0.00	35.7	32.1	0.40	0.40	1504	66	0.90
December	0.55	0.23	0.00	39.5	37.5	0.43	0.43	1452	69	0.95
Jan Retro	0.37	0.26	0.16	39.4	39.8	0.70	0.69	921	109	1.01
February	0.31	0.23	0.15	26.0	30.7	0.73	0.72	1001	100	1.18
March	0.35	0.26	0.16	31.0	36.2	0.73	0.72	971	103	1.17
April	0.34	0.25	0.16	27.5	36.5	0.74	0.73	936	107	1.33
May	0.29	0.21	0.15	26.6	31.8	0.73	0.72	906	110	1.20
June	0.30	0.23	0.15	21.8	33.8	0.75	0.74	898	111	1.55

* recovery load presented in terms of 100,000 Btu/day

Table 62: Site SD2

	Daily Average					Monthly Averages				
	Gas Use	Rec Load	Elec Use	Number	Hot Water	"EF"	"EF"	Gas Btu/	HW gal/	HW gal/
	therms	therms*	kWh	of draws	(HW) gals	Gas only	Site	gal HW	therm	draw
May	0.52	0.26	0.00	84.2	53.1	0.51	0.51	980	102	0.63
June	0.42	0.21	0.00	76.2	46.8	0.50	0.50	901	111	0.61
July	0.37	0.17	0.00	59.8	41.8	0.47	0.47	883	113	0.70
August	0.37	0.18	0.00	64.0	42.7	0.47	0.47	878	114	0.67
September	0.28	0.12	0.00	27.2	28.6	0.43	0.43	987	101	1.05
October	0.36	0.17	0.00	27.4	35.3	0.46	0.46	1033	97	1.29
November	0.46	0.22	0.00	38.7	41.2	0.47	0.47	1110	90	1.06
December	0.57	0.29	0.00	44.3	50.3	0.52	0.52	1133	88	1.14
January	0.62	0.32	0.00	62.9	54.5	0.52	0.52	1134	88	0.87
Jan Retro	0.55	0.38	0.15	74.6	74.7	0.69	0.68	735	136	1.00
February	0.51	0.37	0.15	81.1	72.7	0.72	0.72	706	142	0.90
March	0.49	0.36	0.15	81.2	72.0	0.72	0.72	683	146	0.89
April	0.41	0.29	0.13	78.6	60.9	0.70	0.69	672	149	0.77
May	0.40	0.28	0.13	81.8	63.2	0.70	0.69	639	157	0.77
June	0.43	0.32	0.13	83.5	73.0	0.73	0.73	587	170	0.88

* recovery load presented in terms of 100,000 Btu/day

Table 63: Site SD3

	Daily Average					Monthly Averages				
	Gas Use therms	Rec Load therms*	Elec Use kWh	Number of draws	Hot Water (HW) gals	"EF" Gas only	"EF" Site	Gas Btu/ gal HW	HW gal/ therm	HW gal/ draw
June	0.24	0.09	0.00	21.6	28.5	0.37	0.37	857	117	1.32
July	0.21	0.07	0.00	19.9	26.9	0.35	0.35	793	126	1.35
August	0.17	0.05	0.00	14.7	20.5	0.31	0.31	845	118	1.39
September	0.23	0.06	0.00	8.1	17.8	0.27	0.27	1294	77	2.19
October	0.28	0.09	0.00	15.1	22.5	0.32	0.32	1252	80	1.49
November	0.34	0.12	0.00	21.4	27.9	0.36	0.36	1203	83	1.30
December	0.36	0.13	0.00	21.1	28.5	0.37	0.37	1266	79	1.35
January	0.34	0.11	0.00	19.1	23.5	0.34	0.34	1439	69	1.23
February	0.33	0.11	0.00	17.5	23.6	0.33	0.33	1419	70	1.35
Feb Retro	0.15	0.11	0.16	14.1	27.9	0.72	0.70	552	181	1.98
March	0.16	0.12	0.16	17.0	29.9	0.74	0.72	520	192	1.76
April	0.13	0.09	0.16	15.2	25.5	0.72	0.69	507	197	1.68
May	0.15	0.11	0.17	13.7	29.3	0.71	0.69	514	195	2.14
June	0.19	0.14	0.18	18.7	37.8	0.73	0.70	493	203	2.02

* recovery load presented in terms of 100,000 Btu/day

Table 64: Site SD4

	Daily Average					Monthly Averages				
	Gas Use	Rec Load	Elec Use	Number	Hot Water	"EF"	"EF"	Gas Btu/	HW gal/	HW gal/
	therms	therms*	kWh	of draws	(HW) gals	Gas only	Site	gal HW	therm	draw
May	0.37	0.13	0.00	20.1	24.8	0.35	0.35	1510	66	1.23
June	0.33	0.11	0.00	15.9	22.6	0.34	0.34	1483	67	1.42
July	0.31	0.11	0.00	17.3	22.3	0.34	0.34	1401	71	1.29
August	0.29	0.09	0.00	21.0	20.7	0.31	0.31	1418	71	0.99
September	0.31	0.10	0.00	17.5	22.6	0.33	0.33	1377	73	1.29
October	0.34	0.11	0.00	16.8	22.3	0.34	0.34	1508	66	1.33
November	0.36	0.10	0.00	17.8	19.1	0.29	0.29	1867	54	1.07
December	0.43	0.15	0.00	14.1	23.6	0.35	0.35	1822	55	1.68
Dec Retro	0.19	0.16	0.00	8.8	36.9	0.86	0.86	505	198	4.22
January	0.19	0.17	0.10	11.0	37.2	0.88	0.87	513	195	3.37
February	0.20	0.18	0.14	11.6	39.9	0.89	0.87	512	195	3.43
March	0.20	0.18	0.10	13.6	41.6	0.89	0.88	492	203	3.06
April	0.17	0.15	0.09	10.4	36.7	0.89	0.87	459	218	3.52
May	0.17	0.15	0.09	12.9	39.4	0.88	0.86	435	230	3.05
June	0.16	0.14	0.08	14.3	38.1	0.88	0.86	422	237	2.66

* recovery load presented in terms of 100,000 Btu/day

Table 65: Site SD5

	Daily Average					Monthly Averages				
	Gas Use	Rec Load	Elec Use	Number	Hot Water	"EF"	"EF"	Gas Btu/	HW gal/	HW gal/
	therms	therms*	kWh	of draws	(HW) gals	Gas only	Site	gal HW	therm	draw
May	0.54	0.31	0.00	56.4	87.7	0.57	0.57	615	163	1.55
June	0.48	0.27	0.00	53.0	88.0	0.56	0.56	549	182	1.66
July	0.38	0.21	0.00	45.1	73.6	0.55	0.55	514	195	1.63
August	0.37	0.20	0.00	47.3	75.6	0.55	0.55	485	206	1.60
September	0.39	0.22	0.00	47.0	77.8	0.56	0.56	504	198	1.65
October	0.48	0.27	0.00	53.7	84.6	0.57	0.57	568	176	1.58
November	0.61	0.35	0.00	59.5	92.5	0.57	0.57	661	151	1.55
December	0.65	0.37	0.00	55.5	87.5	0.57	0.57	748	134	1.58
January	0.81	0.47	0.00	70.0	100.9	0.58	0.58	801	125	1.44
Jan Retro	0.84	**		83.7	96.3			867	115	1.15
February	0.81	0.52	0.08	77.9	91.4	0.65	0.65	887	113	1.17
March	0.76	0.49	0.06	74.7	88.3	0.64	0.64	860	116	1.18
April	0.67	0.43	0.05	68.1	84.2	0.63	0.63	797	125	1.24
May	0.68	0.43	0.05	77.1	91.7	0.64	0.64	737	136	1.19
June	0.45	0.28	0.05	67.8	72.2	0.61	0.61	629	159	1.07

* recovery load presented in terms of 100,000 Btu/day

** damaged thermocouple after water heater replacement

Table 66: Site SD6

	Daily Average					Monthly Averages				
	Gas Use	Rec Load	Elec Use	Number	Hot Water	"EF"	"EF"	Gas Btu/	HW gal/	HW gal/
	therms	therms*	kWh	of draws	(HW) gals	Gas only	Site	gal HW	therm	draw
May	0.27	0.15	0.00	33.3	40.9	0.56	0.56	649	154	1.23
June	0.24	0.13	0.00	26.9	39.4	0.54	0.54	597	168	1.46
July	0.21	0.12	0.00	19.7	37.7	0.54	0.56	550	182	1.91
August	0.19	0.11	0.00	15.5	38.3	0.60	0.62	487	205	2.47
September	0.22	0.15	0.00	17.6	49.4	0.66	0.68	452	221	2.81
October	0.28	0.20	0.00	25.4	59.7	0.64	0.71	471	212	2.35
November	0.35	0.17	0.00	34.0	44.9	0.47	0.48	788	127	1.32
December	0.42	0.21	0.00	35.1	48.8	0.49	0.51	853	117	1.39
January	0.47	0.25	0.00	45.3	55.5	0.51	0.52	852	117	1.22
Jan Retro	0.32	0.21	0.22	39.9	40.4	0.63	0.63	795	126	1.01
February	0.35	0.22	0.22	37.9	45.0	0.64	0.63	773	129	1.19
March	0.36	0.24	0.22	43.5	48.6	0.65	0.64	747	134	1.12
April	0.31	0.20	0.21	32.0	43.8	0.65	0.63	713	140	1.37
May	0.27	0.16	0.21	33.1	36.3	0.62	0.60	731	137	1.10
June	0.27	0.17	0.20	37.1	37.5	0.63	0.62	718	139	1.01

* recovery load presented in terms of 100,000 Btu/day

Appendix O: Distribution System Field Survey Responses

Background and Objectives

New homes being built in California are significantly larger and have more amenities than those California homes built twenty to thirty years ago. One amenity increasingly common is an abundance of hot water consuming fixtures. Homes with three and four bathrooms with multiple sinks, multi-head showers, whirlpool tubs, and bar sinks are just a few of the hot water consuming fixtures commonly seen in new homes. As fixtures are added, the plumbing code requires that hot water line sizes increase to handle the unlikely scenario of simultaneous hot water demand from each use point. Larger houses and oversized lines result in a greater volume of water stored in the lines. If the hot water lines fully cool off between draws, the entire volume of the line must be purged before heated water arrives from the water heater.

The performance of residential hot water distribution systems is dependent upon many factors including:

- hot water usage characteristics (magnitude, profile, flow rates, use temperature)
- distribution system configuration (main and branch, "home run", hybrid[9], point of use, or recirculation)
- piping configuration (material, length and diameter)
- location of hot water pipes and ambient conditions surrounding the pipes
- use of insulation
- location of hot water fixtures relative to the water heater
- recirculation system controls

All these factors play a role in determining how efficiently hot water is transported from the water heater to the end use points. Hot water distribution system performance is clearly a

[9] A hybrid system is defined as a main and branch system with one or more manifolds located remotely from the water heater.

complicated issue since the same house may perform very differently based on household usage characteristics (time of day usage patterns, clustering of draws, use temperature, use of tubs, etc.)

Ongoing research under the California Energy Commission's PIER Water Heating project is focusing on developing detailed laboratory data on pipe heat loss performance, validation of existing distribution system models, and improved characterization of hot water draws and use patterns. A key component in improving the understanding of hot water distribution system (HWDS) performance is better defining how systems are currently being installed. To accomplish this, Davis Energy Group and Amaro Construction are collaborating to implement a field survey of new California production homes. A goal for one hundred homes statewide are targeted for survey. This builds on a 2006 sixty home field study also funded by PIER. Both of these studies contribute to an an improved understanding of HWDS performance.

Field Survey Development

The goal of the field survey is to gather a broad overview of typical HWDS installation practice in California production homes. The geographic extent of the survey will cover all of California, but focus on area with significant construction activity. Whereas the 2006 60-house study attempted to gather target slices of the market (as outlined in the "survey targets" below), going into this work, we realized that the stunted construction market was going to make this effort challenging. Our expectation for the current study was to get a broad geographic picture, realzing that in some areas that would be little or no construction activity.

2006 Study Survey Targets

Northern Sacramento Valley: ~5 houses

Bay Area (S.F, East Bay, South Bay): 5 to 10 houses

Central Valley (Sacramento to Bakersfield): 20 to 25 houses

Southern California coastal (L.A. and S.D.): 5 to 15 houses

Southern California inland (Riverside to desert regions): 10 to 15 houses

Constraints on the surveyed sites include the following:

- All single family detached
- Conditioned floor area (ranging from 1,200 – 4,000 ft^2, average= 2,200-2,500 ft^2)
- Our goal is to have no more than three houses per plumbing contractor (we may need flexibility in the 3 home limit in case large contractors dominate a market)
- Target survey segmentation into the following subsets
    - One and two-story houses: Total of 60, with minimum of 20 each
    - Conventional main and branch systems: 20-35 sites

- Hybrid systems: ~5-15 sites
- Parallel piping systems: ~5 sites
- Recirculation systems: 5-15 sites, with 2-5 demand recirculation (depending upon their prevalence in the field)
- Largely underslab piping: ~5-10 sites

The survey will focus on the following key elements:

- Site characterization: location, builder, plumber, floor area, 1 or 2 story, etc
- Water heater characteristics: size, type, Energy Factor, volume, location, etc
- Piping system: sketch and tabulation of each unique[10] hot water line
- Hot water use points: fixture type
- Recirculation system type (if installed): model #, pump, controls (if available)

Site identification will utilize a variety of resources to identify sites including:

- Communications with builder contacts and HERS rater on current projects
- Builder website review
- Leads from vendors and plumbers

Field data will be collected on a paper survey form and transferred to an EXCEL file for data analysis purposes. In addition to completing the inputs on the survey form, the field survey process will include photos of installation details, notes from any site communications with builder superintendents and/or plumbing subcontractors, and a graphical rendering of the plumbing layout corresponding to the tabulated individual pipe element data.

Data Analysis and Reporting

Field survey results will provide a sample of data on a variety of HWDS's currently installed in new California production homes. The main goal in evaluating the data is to generate a better

[10] A "unique" element includes pipe material, diameter, environmental location (e.g. under slab, attic, interior wall, conditioned space etc), and presence of insulation. For piping installed in attics, an estimate was made of what fraction of the pipe element would be covered by attic insulation.

understanding of how these systems are being installed and how "efficiently" the systems are configured. The resulting survey data will be compiled in a field survey report. The report will quantify the following:

- entrained volume between the water heater and each fixture
- percentage of piping under ground, in attic, interior cavities, etc
- piping materials used
- recirculation system types and controls
- number and type of hot water fixtures in new homes
- use of pipe insulation

In addition qualitative information will be obtained, when possible, regarding options that may affect HWDS performance, and other industry trends. This may include issues such as end use fixture options and quality of plumbing installation (insulation properly installed, could hot water piping runs be shorter, are attic runs buried in insulation, etc).

Appendix P: Single Family Construction Plumbing Layout Practices Field Survey Photos

The following series of photographs contains images from the Single Family Construction Plumbing Layout Practices Field Survey. The photos convey some of the common practices observed in the field. The most commonly observed piping material was PEX piping, due to its low cost and ease of installation.

Figure 59 shows the state of construction of a typical home that was surveyed (pre-drywall).

Figure 59: Typical House Construction Stage When Plumbing Survey Completed

Figure 60 shows a common support technique for termination of PEX piping. Since PEX is fairly flexible (especially 1/2” piping), the support is helpful in providing rigidity as the pipe penetrates the drywall.

Figure 60: PEX Tubing Terminal Bend Supports

Figure 61 shows a common termination technique for PEX piping.

Figure 61: PEX Transition to Copper Stubout Elbow

Figure 62 shows a garage located central home run manifold. These home run systems were much more common in the 2006 survey effort, and have now been largely replaced by the mini-manifolds (due to cost). A key insulation detail of the central home run approach is minimizing the length of pipe between the water heater and the manifold. The larger ¾″ or 1″ pipe that feeds the manifold contains most of entrained volume in a home run system. Advantages of the central design is having all the manifold connections at a single accessible location, with the ability to shut off individual circuits if servicing is needed.

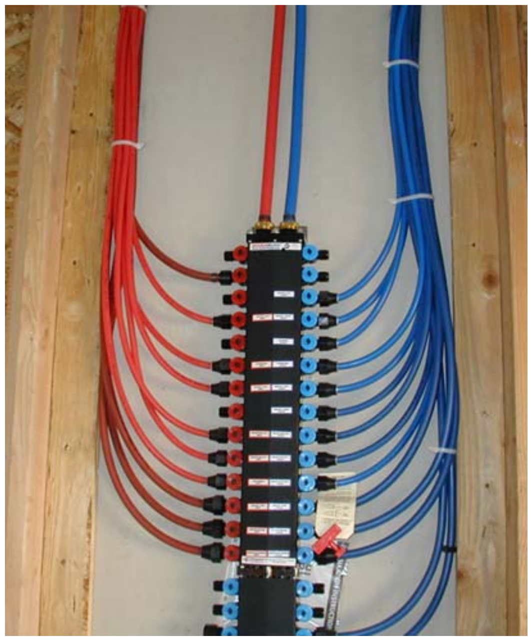


Figure 62: Central Home Run Manifold

Figure 63 shows the bundling of PEX piping, which is not uncommon with home run installations. Although it maintains a tight bundle of tubing, pipe heat loss is generally higher than for an individual pipe, since neighboring tubes are likely filled with ambient temperature water. Bundling also has been observed to result in a less direct route to the use point, as the bundle is often maintained longer than is necessary.

Figure 63: PEX Tubing Bundling (Most Common With Home Run Approach)

Figure 64 shows the common plastic mini-manifold, observed in a large number of sites. The manifold is fed by a ¾″ or 1″ trunk line, with ½″ feeder lines going to nearby use points. The manifold shown in Figure 6 is a flow through manifold, as the trunk line continues to feed another manifold. Copper and brass mini-manifolds were also found, but the plastic were the most common.

Figure 64: Plastic Mini-Manifolds

Figure 65 shows an insulated mini-manifold. Generally the lines feeding the manifolds are not insulated. This may have been a recirculation system.

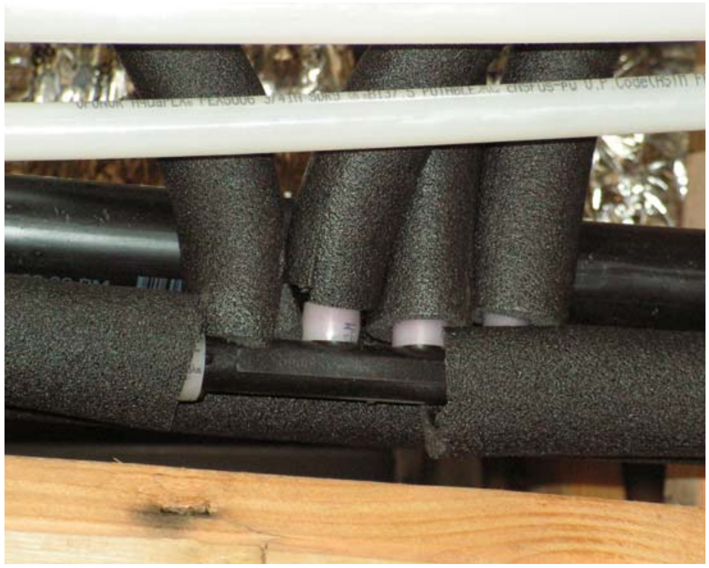


Figure 65: Insulated Plastic Mini-Manifolds

Figure 66 shows a small brass mini-manifold.

Figure 66: Brass Mini-Manifold

Figure 67 shows a PEX trunk and branch configuration where the main trunk line (3/4″ or 1″) is feeding the clothes washer, and then continuing horizontally to feed the neighboring utility sink and additional downstream use points.

Figure 67: PEX Line Feeding Clothes Washer And Downstream Use Points

Figure 68 shows plumbing runs from one of the few sites where CPVC piping was used.

Figure 68: CPVC Distribution System Piping

Figure 69 through Figure 71 show a house with an tankless water heater mounted on the exterior of the garage wall. Exterior mounted units offer some advantages (e.g. venting, possibly minimized gas line length), but care needs to be taken in locating the unit. In the example shown, the hot water line leaving the unit goes up above the garage, and traverses across the garage to the house. This represents a significant volume of water entrained in the pipe before even entering the house. If the line is cold, it will take time to purge the cold water out of the line. The waiting time (and water waste) is compounded by a tankless unit which has an additional time delay in coming up to temperature from a cold start. Intelligent location of the tankless unit and the hot water use points (architectural layout of the house) will minimize any of the wait time issues.

Figure 69: Exterior Mounted Tankless Water Heater

Figure 70: Interior (Garage) View of Exterior Mounted Tankless

Figure 71: Long Plumbing Run Across Garage From Exterior Tankless to House

Appendix Q: Single Family Construction Plumbing Layout Practices Site Field Summary

Site ID #	Distribution System Type	# of Stories	Floor Area (ft2)	# of Hot Water Use points	Number of Bathrooms	Avg gal to Use Point	Max Length to Use Point (ft)	Length of 1" piping (ft)
28	CPVC Trunk & Branch	2	1807	11.0	2.5	0.93	61	12.5
29	CPVC Trunk & Branch	2	2111	13.0	3.0	0.64	44.5	3.5
30	CPVC Trunk & Branch	2	2389	14.0	3.0	0.53	66.5	3.5
31	CPVC Trunk & Branch	2	2156	13.0	2.5	1.41	91.5	0.0
69	Copper Trunk & Branch	1	794	5.0	1.0	0.56	29	0.0
70	Copper Trunk & Branch	1	581	5.0	1.0	0.59	29	0.0
	Average	**1.67**	**1640**	**10.2**	**2.2**	**0.78**	**53.3**	**3.3**
	Average gallons/ 1000 ft2 of floor area					**0.47**		
1	PEX Trunk & Branch	2	2900	17.0	3.0	0.74	88	4.0
2	PEX Trunk & Branch	1	1919	12.0	2.0	0.87	78	0.0
3	PEX Trunk & Branch	1	1543	10.0	2.0	0.95	62	22.0
4	PEX Trunk & Branch	1	1919	10.0	2.0	0.81	53	17.0
24	PEX Trunk & Branch	1	1260	9.0	2.0	0.93	63.5	0.0
34	PEX Trunk & Branch	1	2050	13.0	2.5	1.21	94	0.0
35	PEX Trunk & Branch	2	2484	13.0	2.5	1.21	94	0.0
41	PEX Trunk & Branch	1	1780	9.0	2.0	0.78	60	0.0
42	PEX Trunk & Branch	1	1564	9.0	2.0	0.80	58	0.0
43	PEX Trunk & Branch	1	1239	9.0	2.0	1.05	82	0.0
12b	PEX Trunk & Branch	1	1450	10.0	2.0	0.88	67	21.5
69b	PEX Trunk & Branch	1	1662	10.0	2.0	0.88	69	0.0
70b	PEX Trunk & Branch	2	1906	11.0	2.5	0.82	66	0.0
71b	PEX Trunk & Branch	2	2162	13.0	3.0	1.12	82	0.0
72b	PEX Trunk & Branch	2	1363	11.0	2.5	0.52	51	0.0
84b	PEX Trunk & Branch	2	2532	12.0	2.5	0.73	58	0.0
85b	PEX Trunk & Branch	2	2420	11.0	2.5	1.19	101	0.0
95b	PEX Trunk & Branch	2	1751	11.0	2.5	0.82	65	0.0
	Average	**1.44**	**1884**	**11.1**	**2.3**	**0.91**	**71.7**	**3.6**
	Average gallons/ 1000 ft2 of floor area					**0.48**		
80b	Copper Recirculation	2	3114	13.0	3.0	1.23	86	9.5
81b	Copper Recirculation	2	3486	15.0	3.0	1.16	78	3.5
82b	Copper Recirculation	2	3037	14.0	3.0	1.69	86	6.5
83b	Copper Recirculation	1	2222	14.0	3.0	1.75	124	21.5
86b	PEX Recirculation	2	3359	14.0	4.5	0.82	71	0.0
98	PEX Recirculation	2	2295	14.0	3.0	0.67	71	17
68b	PEX Recirculation	1	1794	11.0	2.0	0.96	67	27.5
	Average	**1.71**	**2758**	**13.6**	**3.1**	**1.18**	**82.9**	**12.2**
	Average gallons/ 1000 ft2 of floor area					**0.43**		
74b	PEX Home Run	1	1995	9.0	2.0	0.56	58	0.0
75b	PEX-HR	1	2000	10.0	2.0	0.58	52	0.0
89b	PEX-HR	1	1500	10.0	2.0	0.47	51	0.0
	Average	**1.00**	**1832**	**9.7**	**2.0**	**0.54**	**53.5**	**0.0**
	Average gallons/ 1000 ft2 of floor area					**0.29**		

Site ID #	Distribution System Type	# of Stories	Floor Area (ft2)	# of Hot Water Use points	Number of Bathrooms	Avg gal to Use Point	Max Length to Use Point (ft)	Length of 1" piping (ft)
7	PEX Hybrid	1	1841	9.0	2.0	0.74	57	0.0
8	PEX Hybrid	2	2817	10.0	2.0	0.56	81	0.0
10	PEX Hybrid	1	2334	15.0	3.0	0.62	58	0.0
11	PEX Hybrid	1	1878	10.0	2.0	0.76	64	0.0
12	PEX Hybrid	1	1878	10.0	2.0	0.72	64	0.0
13	PEX Hybrid	2	2530	15.0	3.0	1.29	76	24.0
14	PEX Hybrid	1	1644	10.0	2.0	1.61	87	34.0
15	PEX Hybrid	1	1947	10.0	2.0	0.77	61	23.0
16	PEX Hybrid	1	1856	10.0	2.0	0.48	35	5.0
17	PEX Hybrid	1	1525	10.0	2.0	0.89	61	7.0
18	PEX Hybrid	1	2400	10.0	2.0	1.52	82	20.0
19	PEX Hybrid	1	1650	10.0	2.0	0.84	63	12.5
20	PEX Hybrid	1	1630	10.0	2.0	1.09	73	0.0
21	PEX Hybrid	1	1931	10.0	2.0	1.42	73	35.5
22	PEX Hybrid	1	1802	10.0	2.0	1.28	73	17.0
25	PEX Hybrid	2	1930	13.0	2.5	0.89	69	0.0
26	PEX Hybrid	1	2145	15.0	3.5	1.18	71	23.0
27	PEX Hybrid	2	4027	14.0	3.5	1.01	67	23.0
32	PEX Hybrid	2	2579	13.0	2.0	0.74	50.5	14.0
33	PEX Hybrid	2	2916	10.0	2.0	1.22	78	25.0
36	PEX Hybrid	2	3437	14.0	2.5	0.81	49	19.5
37	PEX Hybrid	2	2196	13.0	3.0	1.02	71	0.0
38	PEX Hybrid	1	1303	10.0	2.0	1.57	69	49.0
39	PEX Hybrid	1	1900	10.0	2.0	0.96	54	29.0
40	PEX Hybrid	2	2664	13.0	2.5	0.91	69	4.0
44	PEX Hybrid	2	1483	11.0	2.5	0.77	77	0.0
45	PEX Hybrid	2	1387	11.0	2.5	0.68	55	0.0
48	PEX Hybrid	1	2068	11.0	2.0	1.32	130	0.0
49	PEX Hybrid	1	2138	10.0	2.0	1.11	109	0.0
50	PEX Hybrid	1	2071	11.0	2.0	0.79	59	0.0
51	PEX Hybrid	1	2732	14.0	3.0	1.04	100	0.0
52	PEX Hybrid	1	2210	13.0	2.5	1.48	89	14.0
53	PEX Hybrid	2	2768	13.0	2.5	1.12	58	30.5
54	PEX Hybrid	1	1477	11.0	2.0	0.56	43	0.0
55	PEX Hybrid	2	2496	14.0	3.0	1.50	90	37.0
56	PEX Hybrid	2	2504	14.0	3.0	1.51	47	25.5
57	PEX Hybrid	2	3570	19.0	4.0	1.28	76	34.5
58	PEX Hybrid	2	3695	15.0	3.0	1.23	79	15.5
59	PEX Hybrid	1	1595	11.0	2.0	0.82	69	1.5
60	PEX Hybrid	1	1859	11.0	2.0	0.81	56	4.0
66	PEX Hybrid	2	2050	18.0	4.0	1.03	67	21.5
67	PEX Hybrid	2	2350	14.0	3.5	1.61	108	31.0
68	PEX Hybrid	1	2731	16.0	3.0	0.73	67	0.0
66b	PEX Hybrid	1	1831	12.0	2.5	0.73	65	0.0
67b	PEX Hybrid	2	1515	11.0	2.5	0.83	59	0.0
73b	PEX Hybrid	1	1711	10.0	2.0	0.47	57	0.0
76b	PEX Hybrid	1	1558	9.0	2.0	0.96	49	0.0
77b	PEX Hybrid	2	1883	10.0	2.5	0.85	65	12.0
78b	PEX Hybrid	2	2224	14.0	3.0	0.43	48	0.0
79b	PEX Hybrid	1	1820	11.0	2.0	0.69	52	0.0
87b	PEX Hybrid	2	2246	13.0	3.0	0.67	65	0.0
88b	PEX Hybrid	1	2004	10.0	2.0	0.80	63	0.0
90b	PEX Hybrid	2	1820	11.0	2.5	0.46	46	0.0
91	PEX Hybrid	1	1951	10.0	2.0	0.88	68	12.7
92	PEX Hybrid	1	1820	10.0	2.0	0.92	53	31.0
93	PEX Hybrid	2	2317	14.0	3.0	1.38	92	28.5
55b	PEX Hybrid	2	2496	14.0	3.0	1.43	89	36.0
56b	PEX Hybrid	2	2504	13.0	3.0	1.44	92	24.0
94b	PEX Hybrid	1	2597	12.0	2.0	0.57	43	6.0
96b	PEX Hybrid	1	2983	13.0	2.0	0.74	63	5.0
97	PEX Hybrid	1	1952	9.0	2.0	0.90	72	0.0
99	PEX Hybrid	1	1684	10.0	2.0	0.85	75	0.0
	Average	**1.42**	**2175**	**11.9**	**2.4**	**0.97**	**68.4**	**11.9**
	Average gallons/ 1000 ft2 of floor area					**0.45**		

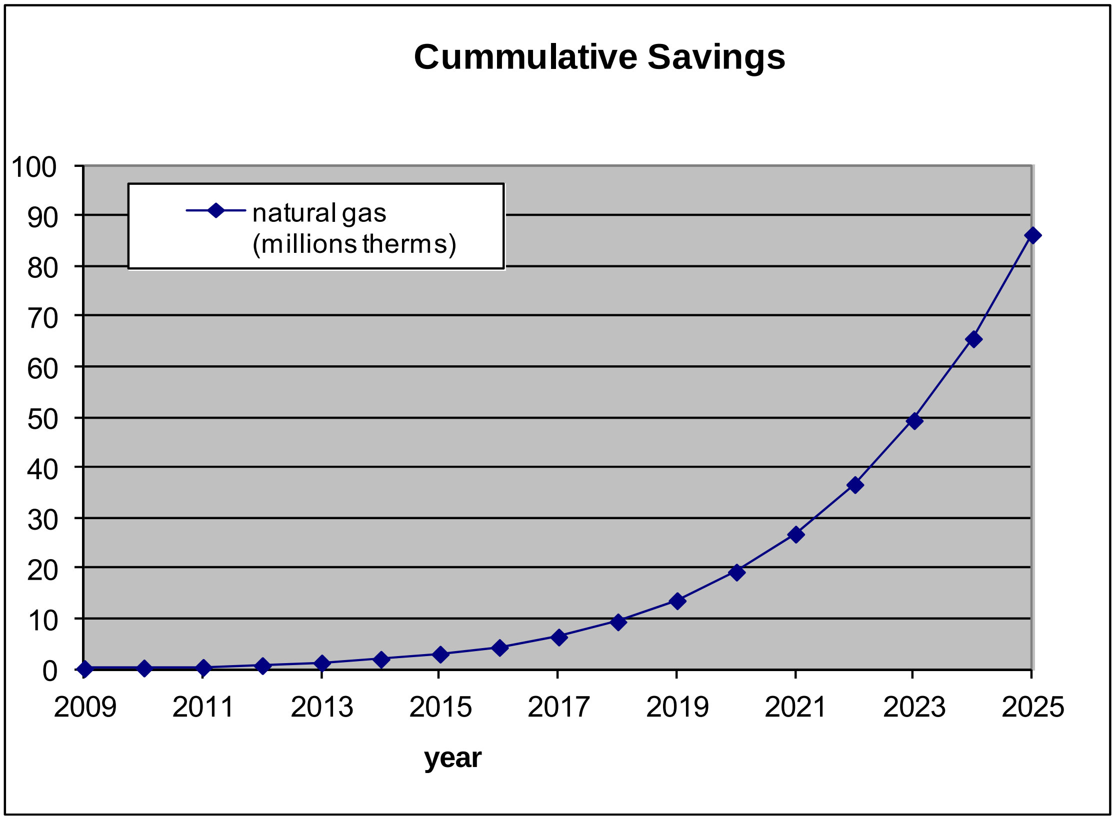
Appendix R: Program Savings Projections by LBNL

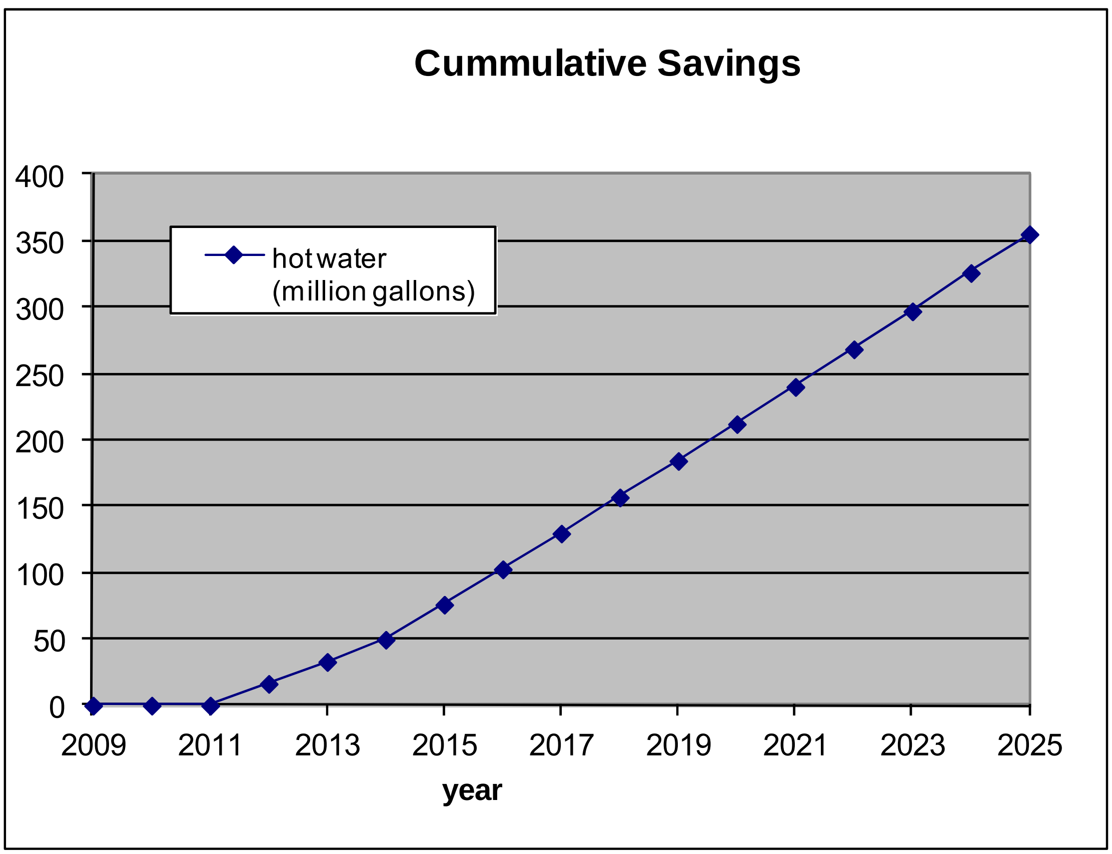
Annual Yearly Savings & Emissions Reductions from New Water Heaters

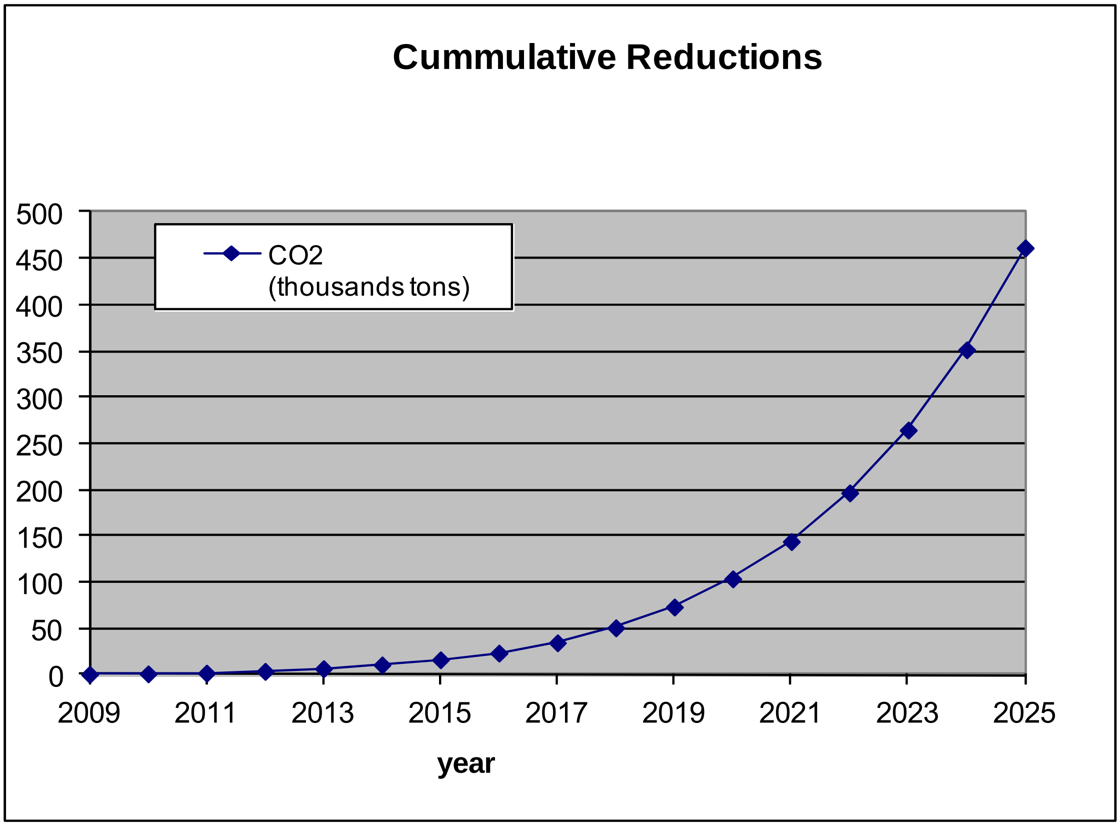
	total					percent of basecase				
Year	natural gas (millions therms)	electricity (MWh)	CO2 (thousands tons)	NOx (thousands lbs)	hot water (million gallons)	natural gas	electricity	CO2	Nox	hot water
2009	0.1	2.9	1	0.2	0.0	0.1%	0.1%	0.1%	0.1%	0.0%
2010	0.1	4.2	1	0.2	0	0.1%	0.1%	0.1%	0.1%	0.0%
2011	0.1	3.3	1	0.2	0	0.1%	0.1%	0.1%	0.1%	0.0%
2012	0.4	-259	2	0.6	16	0.3%	-7%	0.2%	0.3%	0.1%
2013	0.5	-447	3	0.9	17	0.4%	-11%	0.3%	0.4%	0.1%
2014	0.7	-687	4	1.3	17	0.5%	-15%	0.5%	0.5%	0.1%
2015	1.0	-992	6	1.8	26	0.7%	-19%	0.7%	0.7%	0.2%
2016	1.3	-1,717	7	2.3	27	1.0%	-30%	0.9%	1.0%	0.2%
2017	2.1	-2,807	11	3.6	27	1.5%	-45%	1.4%	1.5%	0.2%
2018	3.0	-4,187	16	5.3	27	2.1%	-63%	2.0%	2.1%	0.2%
2019	4.2	-5,929	23	7.3	27	2.9%	-82%	2.7%	2.9%	0.2%
2020	5.7	-8,115	30	9.9	28	4.0%	-104%	3.6%	4.0%	0.2%
2021	7.5	-10,857	40	13.2	28	5.2%	-128%	4.7%	5.2%	0.2%
2022	9.8	-14,267	53	17.2	28	6.7%	-156%	6.1%	6.7%	0.2%
2023	12.7	-18,508	68	22.2	29	8.6%	-186%	7.9%	8.6%	0.2%
2024	16.2	-23,767	87	28.4	29	11.0%	-220%	10.0%	11.0%	0.2%
2025	20.6	-30,298	110	36.1	29	13.9%	-258%	12.6%	13.9%	0.2%

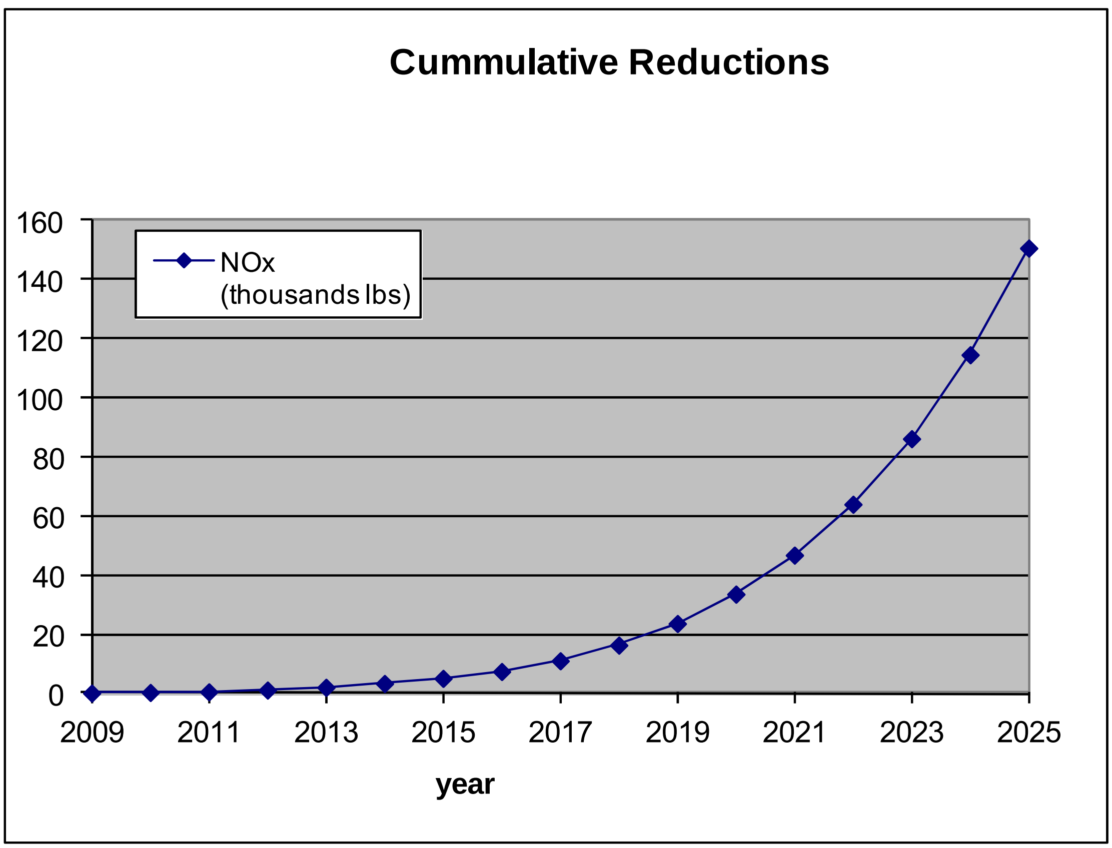
Cummulative Yearly Savings & Emissions Reductions

	total					percent of basecase				
Year	natural gas (millions therms)	electricity (MWh)	CO2 (thousands tons)	NOx (thousands lbs)	hot water (million gallons)	natural gas	electricity	CO2	Nox	hot water
2009	0.1	2.9	1	0.2	0	0.1%	0.1%	0.1%	0.1%	0.0%
2010	0.2	7.1	1	0.4	0	0.1%	0.1%	0.1%	0.1%	0.0%
2011	0.4	10.4	2	0.6	0	0.1%	0.1%	0.1%	0.1%	0.0%
2012	0.7	-248	4	1.2	16	0.1%	-2%	0.1%	0.1%	0.0%
2013	1.2	-695	7	2.2	33	0.2%	-4%	0.2%	0.2%	0.0%
2014	2.0	-1,383	11	3.4	50	0.2%	-6%	0.2%	0.2%	0.1%
2015	3.0	-2,375	17	5.2	76	0.3%	-9%	0.3%	0.3%	0.1%
2016	4.3	-4,092	24	7.5	103	0.4%	-13%	0.4%	0.4%	0.1%
2017	6.4	-6,899	35	11.2	130	0.5%	-18%	0.5%	0.5%	0.1%
2018	9.4	-11,087	51	16.4	157	0.7%	-24%	0.6%	0.7%	0.1%
2019	13.6	-17,015	74	23.8	184	0.9%	-32%	0.8%	0.9%	0.1%
2020	19.3	-25,130	104	33.7	212	1.1%	-41%	1.0%	1.1%	0.1%
2021	26.8	-35,987	144	46.9	240	1.5%	-52%	1.3%	1.5%	0.1%
2022	36.6	-50,255	197	64.1	269	1.8%	-64%	1.7%	1.8%	0.1%
2023	49.3	-68,762	265	86.3	297	2.3%	-78%	2.1%	2.3%	0.1%
2024	65.6	-92,529	352	114.7	326	2.9%	-93%	2.6%	2.9%	0.1%
2025	86.2	-122,827	462	150.8	355	3.6%	-111%	3.2%	3.6%	0.1%


Cummulative Savings
100
90
80
70
60
50
40
30
20
10
0
2009
2011
2013
2015
2017
2019
2021
2023
2025
year
natural gas
(millions therms)


Cummulative Savings
400
350
300
250
200
150
100
50
0
2009
2011
2013
2015
2017
2019
2021
2023
2025
year
hot water
(million gallons)


Cummulative Reductions
CO2
(thousands tons)
500
450
400
350
300
250
200
150
100
50
0
2009
2011
2013
2015
2017
2019
2021
2023
2025
year


Cummulative Reductions
NOx
(thousands lbs)
160
140
120
100
80
60
40
20
0
2009
2011
2013
2015
2017
2019
2021
2023
2025
year